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USAAVSCOM TECHNICAL REPORT

STUDY OF HELICOPTER TRANSMISSION SYSTEM DEVELOPMENT TESTING

SIKORSKY ENGINEERING REPORT SER-50547

JUNE 1968

U. S. ARMY AVIATION SYSTEMS COMMAND
ST. LOUIS, MISSOURI

CONTRACT DAAJ01-68-C-1395(C)

SIKORSKY AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION

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This study represents part of the effort of the Flight Standards and Qualification Directorate and the US Army Aviation Systems Command in preparation of the Army Rotorcraft Engineering Handbook.

This Command generally concurs with the contractor's approach to helicopter transmission development testing, however, some changes and modifications will be made in the official handbook presentations.

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USAAVSCOM Technical Report

June 1968

Study of Transmission System Development Testing

Sikorsky Engineering Report SER-50547

By

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For

Flight Standards and Qualification Directorate
US Army Aviation Systems Command
St. Louis, Missouri

FORWARD

This report covers a study of helicopter transmission development testing conducted for the U.S. Army Aviation Materiel Command (AVCOM) under contract DAA J01-68-C-1395(C).

USA AVCOM technical direction was provided by Mr. L.E. Follis and Mr. H. Schuetz of the Directorate of Research, Development and Engineering. Contracting Officer was Mr. V. Murphy.

The principal investigators for Sikorsky Aircraft were L.R. Burroughs, Assistant Supervisor of the Mechanical Design and Development Section, W.R. Morrissey, Assistant Supervisor of the Aircraft and Armament Test Section, E.I. Gismondi, Supervisor of the Propulsion Systems Test Group, R.W. Caseria, Supervisor of the Statistics and Mathematical Modeling Group and R. Allen of the Transmission Group.

SUMMARY

This report presents the results of a six months study of test service and overhaul experience on the transmission system components of H-3, H-53, and H-54 helicopters. The study was conducted to determine the relative effectiveness of bench tie-down and flight testing in revealing transmission system modes of malfunction or failure.

Failure data for transmissions of all three aircraft were made to determine failure trends and rates of failure. An analysis of these data overhaul information and component costs was conducted to determine the effectiveness of current overhaul practices and recommendations for transmission operating intervals are offered.

An investigation of the relative costs spent on testing, production and spare transmissions overhaul, and modifications (ECP's) has been made for the H-3 and H-53 which undergone full military qualification test programs.

A discussion of the goals of transmission development is included along with a suggested transmission test program.

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DEVELOPMENT TESTING

INTRODUCTION

There is considerable evidence available to indicate that helicopter transmission system reliability and aircraft availability in operational service could be significantly improved by adequate and timely development testing, which must include not only testing but also development and incorporation of design improvements. Since low reliability results in large logistic and maintainability expenditures, it appears that more extensive development testing would be cost effective, not only in decreasing spares requirements but also increasing aircraft avilability early in the operational phase and reducing overall life cycle costs of helicopter systems.

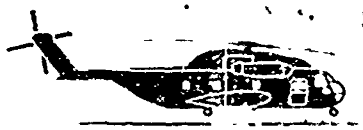
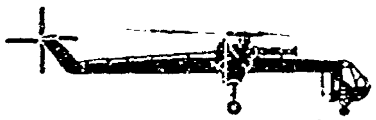
This study was conducted for the U.S. Army Aviation Materiel Command (USAAVOCM) to evaluate the extent to which the types and amount of development testing determines (or regulates) the level of transmission reliability and overall operational effectiveness in the field. The analyses included herein were conducted with actual test and service data to establish the value of each type of testing, to permit meaningful conclusions to be drawn and to provide a sound basis for the recommendation of a better development testing criteria. Reasonably these data and recommendations will be incorporated in a new test specification for helicopter transmission system development.

In addition an evaluation of current service interval (TBO) practices has been made with recommendations for establishing a more logical and cost effective approach.

To determine the relative effectiveness of past and present transmission test program, Sikorsky Aircraft has selected three production aircraft models, the H-3, H-53, and H-54 for which there is considerable test, production, and field service data available. A brief summary of technical data and the type of testing conducted on each aircraft is presented in Table I. The data included in Table I is applicable as of June 1968.

Schematic drawings of the transmission system arrangements and cross-sectional drawings of the main gearboxes for each aircraft are included in Appendix I.

SIKORSKY HELICOPTER DATA

MODEL	AIRCRAFT CONFIGURATION	MILITARY/ COMMERCIAL DESIGNATION	GROSS WEIGHT	NO & TYPE ENGINES	INSTALLED POWER (HP)	TOTAL NO A/C	TOTAL FLIGHT HOURS	TESTING: FLIGHT	TESTING: TIE-DOWN	TESTING: DYNAMIC SYSTEM	TESTING: SUBSYSTEM BENCH
H-3		SH-3 CH-3 HH-3 VH-3 RH-3 S-61L S-61N	21000	2 Turbine GE-T-58	3000	543	730,300	Yes	Yes	Yes	Yes
H-53		CH-53	42000	2 Turbine GE-T-64	7000	126	39,000	Yes	Yes	Yes	Yes
H-54		CH-54 S-64	42000	2 Turbine P & W JFTD-12	8100	45	17,600	Yes	No	Yes	•

•Tail and Intermediate Gearbox - Yes

Main Gearbox - Under Contract

CONCLUSIONS AND RECOMMENDATIONS

Discussion

The (initial) test program(s) for helicopter (and other V/STOL aircraft) power transmission systems should have three (3) primary objectives.

1. To (reasonably) demonstrate that the transmission system components meet their design requirements as established in the aircraft detail specification and applicable military specifications.

   NOTE: These tests are the qualification substantiation tests (or preproduction tests) currently required by military specifications such as MIL-T-5955B and MIL-T-8679.

More importantly, however, the transmission test program should provide sufficient test effort to:

2. Thoroughly develop and "debug" the transmission components.
3. Determine the modes of failure of the transmission system components and demonstrate that all "catastrophic" modes are well out of the planned operating ranges. In conjunction with testing demonstrate that all non-catastrophic modes of failure are detectable.

These latter two objectives require test philosophies that depart from the "must-pass" tests that have (at least in the past) been associated with

the qualification/substantiation tests of the current military test specifications for helicopter transmission.

On the basis of the investigations and analysis conducted during this study, a number of specific conclusions have been drawn. In addition, these conclusions and recommendations can be divided into two basic areas: development and qualification testing and service interval (TBO) practices:

Development Testing

1. The regenerative bench test is the most effective means of developing helicopter transmission components on the basis of the number of problems uncovered (modes of failure) and cost per hour of testing.

2. The tie-down and dynamic test facilities may be very effective and necessary tools in determining the dynamic response and interface problems between transmission and other helicopter systems (i.e., control, rotor, engine, airframe, etc.), but neither are as effective in developing the power train components as the regenerative bench test.

3. Helicopter transmission development test programs should be designed to uncover problem areas. As such the loading (power, thrust, etc.) should be considerably accelerated over normal mission requirements and not based on arbitrary requirements. (See paragraph 4.)

4. The load acceleration used in transmission development tests should be kept within practical limits of deflection and stress. From the test experience on the three models reviewed, the following appear to be the practical maximum limits.

Power	110% to 120% of take-off or maximum rating
Speed	110% of maximum speed
Thrust, Load	120% of maximum anticipated conditions

Loads beyond these limits may (will) produce excessive deflections beyond the point where the anticipated life-load relationships apply thereby producing test results that are no longer meaningful.

5. To obtain sufficient statistical information, the initial bench tests should include several test specimens. While reliability studies indicate an appreciable quantity of gearboxes is required to cover the possible tolerance variations, scatter in strength of components, etc., three or four gearboxes are considered desirable and two units (not including the Dummy or slave) mandatory.

6. The duration of the bench tests is not as important as the approach. It is considerably more effective to conduct two "overstress" development tests introducing the necessary fixes for the test units (and production transmissions) as malfunctions occur rather than conduct a single "must-pass" test at a low mil-spec test requirement.

7. Follow-on development programs for helicopter transmission system components should be included in the original contract or negotiated during the initial prototype program (or contract period) to maintain continuity in the testing and to provide the necessary program to develop "fixes" for the earliest possible incorporation in new production and delivered gearboxes.

8. Requirements for substantiation/qualification "must-pass" tests (if considered mandatory by the procuring agency for granting the authority to initiate production fabrication or deliveries) should be conducted in addition to, but not in place, of properly designed developmental tests.

Service Intervals

1. Constant failure rates observed in a complex component, such as a helicopter transmission, are made up of many failure modes, each of which can have a failure rate other than constant. Debugging or wear-out phenomenon occurs at the component level when one mode of failure, having a debugging or wear-out characteristic, dominates the failure rate of the complex component or when several lesser failure modes with similar failure patterns combine to control the complex component's failure pattern.

2. Low service intervals do not necessarily assure flight safety or aircraft availability. On the contrary, low service intervals necessitate more units per given number

of flight hours, thereby statistically increasing the exposure to failure. In addition, low service intervals result in uneconomical operation and increased maintenance burdens.

3. Current service intervals(TBO's) are arbitrarily established by "must-pass" qualification tests and have little relationship to helicopter transmission "wear out"[1] phenomenon or to component retirement intervals.

4. Service intervals for helicopter transmissions should approach the removal "on-condition" concept providing the transmission development programs have established the modes of failure and demonstrated that these modes are noncatastrophic and detectable. There may be some practical upper limit (calendar or flight hours) for this interval - say 2000 hours or 3 years for military aircraft. This practice, or an actuarial practice such as is sometimes used for aircraft engines, will result in considerably reduced maintenance, overhaul, and spares costs.

5. Spares provisioning for an "on-condition" or high service interval can be established on MTBR or MTBF data.[2]

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(1) See definition on page 32.

(2) One method is suggested in RELIABILITY DISCIPLINES - DETERMINE the OPTIMUM REPLACEMENT TIMES for MAJOR MECHANICAL COMPONENTS of HELICOPTERS - R.W. Caseria, Sikorsky Aircraft SAE Technical Paper 855B April 1964.

CURRENT TEST REQUIREMENTS

The design and test requirements for military helicopter power transmission systems components are for the most part set forth in two general military specifications, MIL-T-5955B and MIL-T-8679.

MIL-T-5955B

This document outlines the "general requirements for transmission systems used in applying primary power." In this Specification, the power transmission system is defined as all part "between the engine(s) and the main or auxiliary rotor hubs. This will be interpreted to include gearboxes, shafting, universal joints, coupling, rotor brake assembly, overrunning . . . clutches, supporting bearings for shafting and any attendant accessory pads or drives."

This specification sets forth the general design requirements for power train components and covers the acceptance (Quality Control) test requirements. Acceptance tests are defined by the specification as "that group of tests conducted . . . to demonstrate end item Quality Control, correct assembly and performance." In addition it specified (in paragraph 4.2.2) that preproduction testing be conducted in accordance with MIL-T-8679.

A suggested revision to MIL-T-5955 (designated "C"), which is currently being reviewed by contractor and Government personnel proposes to incorporate developmental and preproduction test requirements into the specification. In this revision, developmental test requirements are to be prepared by the contractor and approved by the procuring activity.

The preproduction tests as proposed require the testing of a minimum of two samples for 200 hours at the following conditions:

PREPRODUCTION TEST

(MIL-T-5955C)

TIME	POWER	INPUT SPEEDS
10 hours	Min. input	Normal rated RPM
90 hours	Max. input	Maximum rated RPM
15 hours	Min. input	Normal rated RPM
85 hours	Max. input	Maximum rated RPM

The "C" revision would consider that satisfactory completion of the preproduction test would occur when a helicopter transmission component had completed "200 consecutive hours of testing . . . without failure, excessive wear or other damage . . ."

MIL-T-8679

This specification covers the ground testing of helicopters and the components peculiar to helicopters including the development and production acceptance tests for the power transmission system. The specific test requirements for the transmission system are outlined in paragraph 3.7. While the specification states that "the Contractor shall have satisfactorily conducted a transmission bench test . . ." no test requirements are included. Those development tests outlined in this document in some detail are tie-down tests and include:

- .50 hour Preliminary Flight Approval
- .150 hour Preproduction Test
- .250 hour Ground Test (when required by the procuring activity)

Test Spectrum

MIL-T-8679 specified a power loading schedule, based on reciprocating engine ratings, for the above tie-down tests. Each of the tests are to be conducted in 10 hour cycles as follows:

10 HOUR TEST CYCLE

TIME (hrs.)	POWER LEVEL	SPEED
0.5	Take-off*	T.O.
0.5	Idle*	Idle
0.5	Military **	Military
3.0	Normal Rated **	Normal Rated
1.0	90% NRP	Normal Rated
1.0	80% NRP	Normal Rated
2.5	60% NRP	Min. Cruise Speed or 90% N.R. Speed
1.0	Normal Rated	110% N.R. Speed or Max. Permissible Engine Speed

*Cycle 5 min. at T.O. power/speed-

5 min. at idle power/speed

**Cycle 30 min. at Military power/speed -

30 min. at 60% NRP/speed

The tests outlined in both specifications are those specified for the substantiation or qualification of the transmission system. In other words, the minimum requirements that must be passed. Little reference is made to programs that are truly developmental in nature.

Neither Specification covers bench testing, bench tests, when conducted, have always been covered in the aircraft detail specification or contract.

Too often in the past, the procuring agency (and sometimes the Contractor) has considered the preproduction and tie down test programs (perhaps because of the tight funding or scheduling) the only necessary transmission development program. Emphasis is placed on passing the test within a fixed calendar time or number of test hours, thus discouraging proper development of the power train components. This approach can result in a major field logistic problem with the helicopter transmission components in two ways.

----- If the level of the test spectrum is too low, a low transmission reliability too often results - the testing then occurs in the field and serious logistic and retrofit problems are experienced.

----- If too severe a test is conducted and failures occur, the "must-pass" approach often results in holding down the service interval TBO thereby requiring more spares overhauls, etc.

The analysis of the test programs on the three Sikorsky helicopter transmission systems will demonstrate these observations.

ANALYSIS OF TEST PROGRAMS

DISCUSSION

As indicated in Table I, the transmission systems of the three Sikorsky production helicopters selected for this study have been subjected to multilevels* of testing. For all three aircraft, dynamic system tests were conducted on an integrated propulsion/transmission system test facility, which included the engines. Photos of these facilities are included in Appendix A.

The transmission components of two of the aircraft (the H-3 and the H-53) were subjected to extensive tie-down and bench tests as well. The duration of each type of qualification/development testing for each of the power transmission systems is given in Table II below.

TABLE II

TOTAL TEST DURATION

Model	Bench Test (Hours)	Tie-Down Test (Hours)	Dynamic System Test (Hours)	Flight Test (Hours)
H-3	3920	1376	445	4000
H-53	555	500	354	1400
H-54	0	0	624	900

* Multilevels of Testing: i.e., System, Subsystem Component Tests

GROUND TEST PROGRAMS

The ground test programs for each aircraft transmission system are summarized in Table III. Included in this summary are the type of test, duration and test loading. For simplicity in presentation, only the formal bench test programs conducted on the main transmissions are presented. The data is essentially in chronological order and shows the changing philosophy at Sikorsky Aircraft in utilizing the regenerative bench test for the transmission development. Representative test spectra for tie-down, dynamic system and bench tests are included in Appendix A.

Bench Tests

The transmission bench test programs conducted under the initial H-3 and H-53 contracts basically followed the same general pattern and included the following test phases.

Phase I No Load Lubrication Tilt Tests

The test transmission was mounted on a tiltable stand and run at full speed and no load to determine the proper flow of lubricant to each portion of the gearbox under flight attitudes.

Phase II Bevel Gear Pattern Tests

The test and dummy gearboxes were installed in the regenerative test loop and operated at various levels of torque, from 0 to maximum, at a constant low speed to determine proper bevel gear load patterns. The bevel gear teeth were painted with white lead to show load contact.

Phase III "Break-in" Tests

The test and dummy gearboxes were subjected to a break-in in accordance with the production acceptance test procedures (similar to MIL-T-8679, paragraph 3.7.4).

Phase IV 50-Hour Qualification Tests

A 50-hour qualification (or preliminary flight approval test) was conducted on the gearboxes at the endurance test spectrum.

Phase V Endurance Tests

Outlined in Table III.

For the H-54 transmission system, the bench test program was primarily limited to no-load lubrication tests for each gearbox and a 25-hour four-square regenerative bench test on the first stage input section for the main gearbox. No major problem areas were uncovered during these tests.

Tie-Down and Dynamic Systems Tests

Extensive dynamic systems (propulsion, drive train, rotors and controls) tests were conducted for all three aircraft reviewed in this report. For the H-54, the dynamic systems test was the primary development and qualification vehicle for that aircraft's dynamic components.

Both the H-3 and H-53 were subjected to tie-down tests conducted essentially in accordance with the requirements of MIL-T-8679.

FLIGHT TESTING

A review of the transmission malfunctions occurring during the flight test program was also conducted. Particular attention was given to the information available for the H-3 and H-53 aircraft where the tie-down and bench test data were also available.

While the flight test programs more nearly approximate actual service use of a helicopter transmission system, the number of flight hours per month early in a program is necessarily low due to instrumentation requirements, weather, etc. The number of problem areas uncovered in any given calendar period, therefore, is considerably lower than those found in the other tests. Another factor for limiting the effectiveness of flight test (and tie-down and dynamic systems testing as well) is that the initial production engines often do not deliver as much power as later versions. In addition, the cost of flight is considerably higher than those of bench or tie-down testing.

Flight testing is a definite asset in the development of helicopter transmission systems. The investigators do not believe, however, that a flight test program specifically for transmission development is cost effective.

TABLE III

SUMMARY

GROUND TEST PROGRAMS
H-3, H-53 and H-54

MODEL	TEST PROGRAM	DURATION (HOURS)	TEST LOADING	COMMENTS
	Tie-Down Test	1376	MIL-T-8679	
	Dynamic Systems Test	445	Spectrum*	*Test spectra for these tests provide some acceleration (more severity) over aircraft mission requirements
	Bench Tests:			
H-3	S6135-20000	480	Spectrum*	
	S6135-20600	770	Spectrum	
	S6135-21000	500	MIL-T-8679	
	S6135-22000	125	T.O. Power	
	S6135-23000	200	MIL-T-8679	
	S6135-23000	500	Accel. MIL-T-8679	More severe than MIL-T-8679
				NOTE: Considerably more development testing was con ducted in the evolution of the final H-3 gearbox configurations, much of at or above T.O. power
	Dynamic Systems Tests:			
	S6435-20000-012	100	A/C Mission Spectrum	
	S6435-20000-041	240	Cam 7#	Essentially the same as MIL-T-8679
H-54	S6435-20000-042	277	Accel. MIL-T-8679	
	S6435-20500-041	50*	T.O. Power	*Initiated May 1968

TABLE III (cont'd)

SUMMARY

GROUND TEST PROGRAMS
H-3, H-53 and H-54

MODEL	TEST PROGRAM	DURATION (HOURS)	TEST LOADING	COMMENTS
	Tie Down	500	MIL-T-8679	
	Dynamic System	50	Accel. MIL-T-8679	
H-53		304	Survey Tests	Test Spectra less than MIL-T-8679
	Bench Tests:			
	S65351-11000	500	Accel. MIL-T-8679	
	S65350-	500*	"Over stress" Spectrum	*Test spectrum for product improvement program to be initiated June 1968 considerably more severe than MIL-T-8679. Provides life acceleration factor of 4 over mission spectrum. Goal: substantiate 2000 hour service operation in 500 hour test.

For the main gearboxes of both aircraft, the tests of Phases II thru IV were conducted on a "back-to-back" regenerative test stand using a "Test" Gearbox and a "Dummy" (or slave) Box. The intermediate and Tail Rotor Gearboxes for both helicopters were tested in "four square" regenerative test stands. Appendix A includes photographs of these test facilities.

Test Results

A thorough review of all the test programs of Table III was made to determine:

(1) The relative effectiveness of each type of testing and (2) The relative cost of each type of testing.

(a) A comparison was made of tie-down and bench testing. Figure 1 shows the rate of accumulation of modes and total failures verses test hours. These curves are based on the test malfunctions/failures for the main transmission of the H-3 and the H-53. One important fact is to be noted; that is the importance of multiple sample testing. The bench test employed two aircraft transmissions to form the regenerative loop, and as a result more different modes of failures were uncovered faster than the single sample used on tie-down test, although acceleration factors were about equal.

(b) The coincidence of the maximum failure rate both occuring at 100 hours may be explained by the fact

that for both models the two tests started and completed the first 100 hours in the same time span.

(c) To establish an overall cost effectiveness for each type of testing an analysis of the actual costs of the bench, tie-down and dynamic systems test for each aircraft was also made. Since the latter two tests are used to substantiate/develop other aircraft components, the total costs of these programs cannot be reasonably charged against the transmission system. The test costs assigned to transmission testing was established by proportioning the number of transmission failure/malfunctions experienced during the test to the total number of malfunctions experienced on all components during the test. Figure 2 shows the relative costs of three types of ground testing, bench, tie-down, and dynamic system.

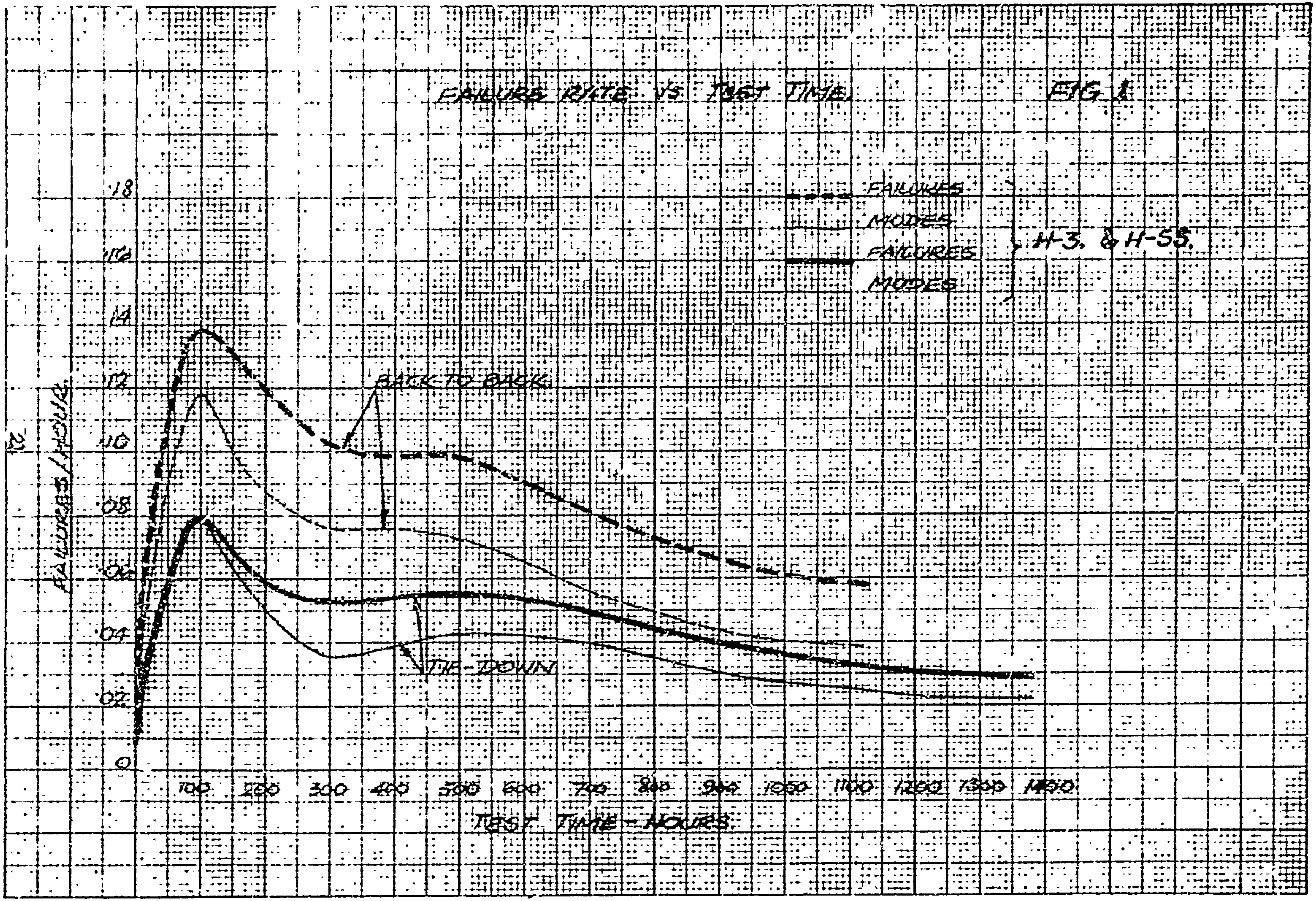
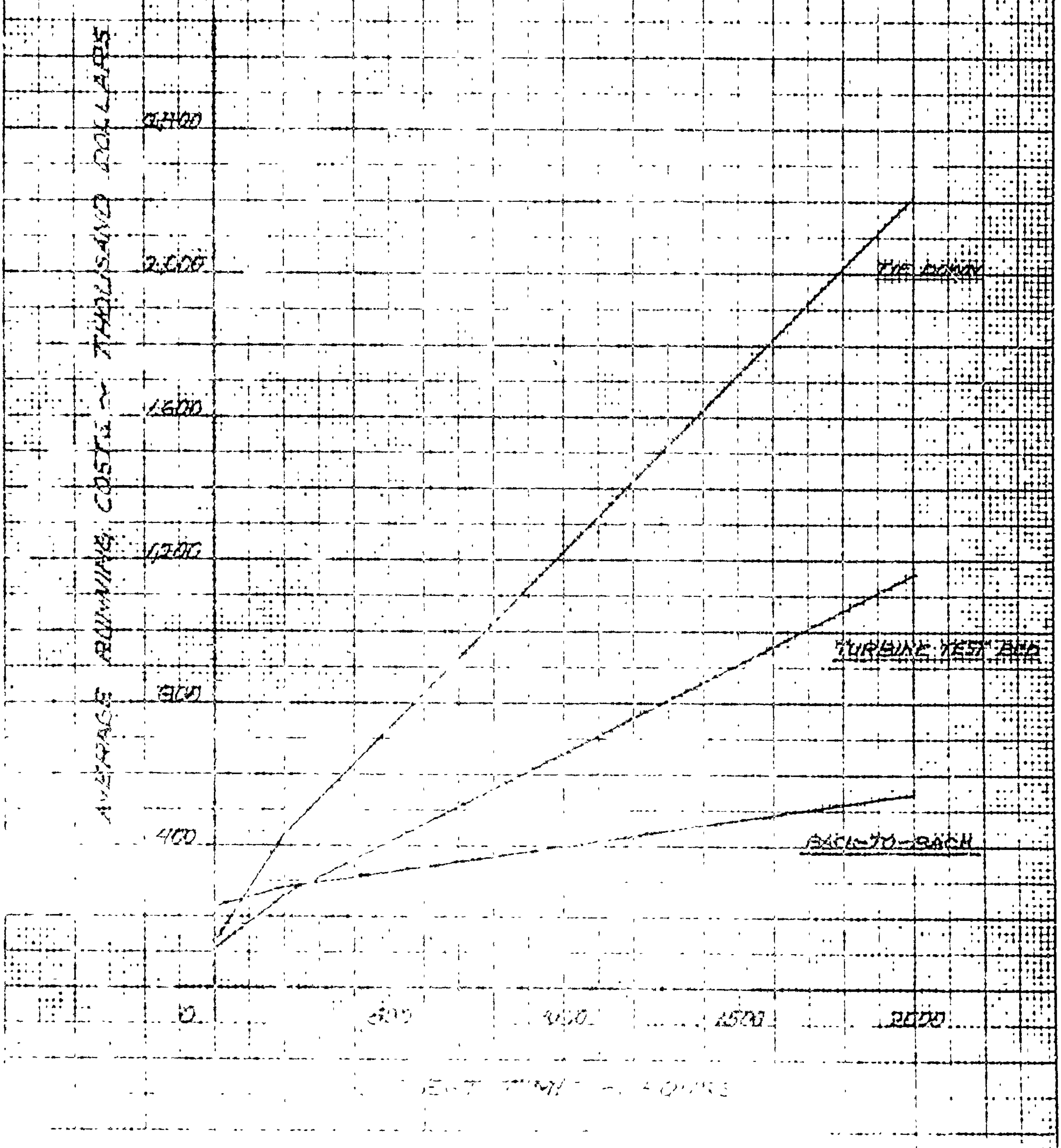

FAILURES RATE VS TEST TIME.
FIG 1
FAILURES
MODES
FAILURES
MODES
H-3, & H-55.
BACK TO BACK
TIE-DOWN
FAILURES / HOUR
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
TEST TIME - HOURS.

FIGURE 2

AVERAGE RUNNING COSTS VS. TEST TIME
FOR MAIN TRANSMISSION



An analysis of the failure and cost data of Figures 1 and 2 was made to establish a relative factor of cost effectiveness for each type of transmission development testing.

For this study, the measure of effectiveness of testing was taken as

$$\eta = \frac{m}{C\,t}$$

where m = modes of failure

C = cost of test

= test hours x cost/hour

t = test duration (months)

From Figures 1 and 2 and the data of Appendix (1) the average measure of effectiveness of each type of testing is

Tie-down Test	η	= 0.6
Dynamic System Test	η	= 0.8
Back-to-Back Test	η	= 2.6

If the "effectiveness" of tie-down testing for main transmission development is set equal to one (TD = 1.0) then:

Tie-down Test	η	= 1.0
Dynamic System Test	η	= 1.3
Back-to-Back Test	η	= 4.3

It is therefore apparent on the basis of these data that extensive and early bench tests will "pay their way" in reducing the number of failures in the tie-down test and early flight test programs.

ANALYSIS OF SERVICE DATA

INTRODUCTION

A review of the service history of each of the three aircraft has been made to determine the mean-time-between failure (MTBF), mean-time-between removal (MTBR), modes of failure, and/or reason for removal of transmission system components. This review was based on the following data:

(a) Sikorsky Aircraft Field Discrepancy Reports

(b) Sikorsky Aircraft Field Service Reports

(c) Overhaul Inspection Reports

(d) U.S. Navy Failure/Unsatisfactory Reports

(e) U.S. Air Force Maintenance Management 66-1 Reports

(f) Aircraft Log Records

For each major subsystem in the transmission system (i.e., gearboxes, drive shafting), the modes of failure and quantity of removals due to each mode were analyzed, and where sufficient data exists, a failure trend analysis was prepared for each mode of failure.

Since the main gearbox is the most complex assembly in the transmission system, most of the service problems are usually associated with it. Its costs and lead time (both production and overhaul) make it the primary logistics problem as well. A review of the H-3, H-53 and H-54 service history indicate this trend. Therefore, the primary effort in the service history review was concentrated on the main transmission.

REVIEW OF SERVICE EXPERIENCE

Figures (3) through (10) give the failure/malfunction trends for

the H-3, H-53 and H-54 main gearboxes respectively. These curves include all gearbox premature removals for the period reviewed including pilot- and maintenance-induced failures or malfunctions. These data indicate that the main transmissions of these aircraft have essentially constant removal/ failure rates. There is strong evidence to indicate other helicopter manufacturers' gearboxes show the same trends after these units have been sufficiently developed.*

Figures (3) through (7) reflect the individual histories of progressive design modifications in the SH-3A, H-3 family of main transmissions. The development of this gearbox can be traced through the increasing MTBFs.

- Figure (3) shows the initial SH-3A production main transmission design to have a constant failure rate with no single dominating mode of failure. (MTBF = 502 hours)

- Figure (4) shows the failure trend of a modified version of this gearbox. The failure trend for this unit exceeds the upper statistical limit of the normally-expected variation about the constant rate. This validates the conclusion that for this gearbox the rate is not constant but is governed by an unusually high early failure rate occurring in the initial hours after installation on the aircraft. Improper preloading of a bearing and failure of a snap-ring were found to be the causes of this

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* Bell Helicopter Company Report Number 205-099-168, dated June 17, 1967

FIGURE 3

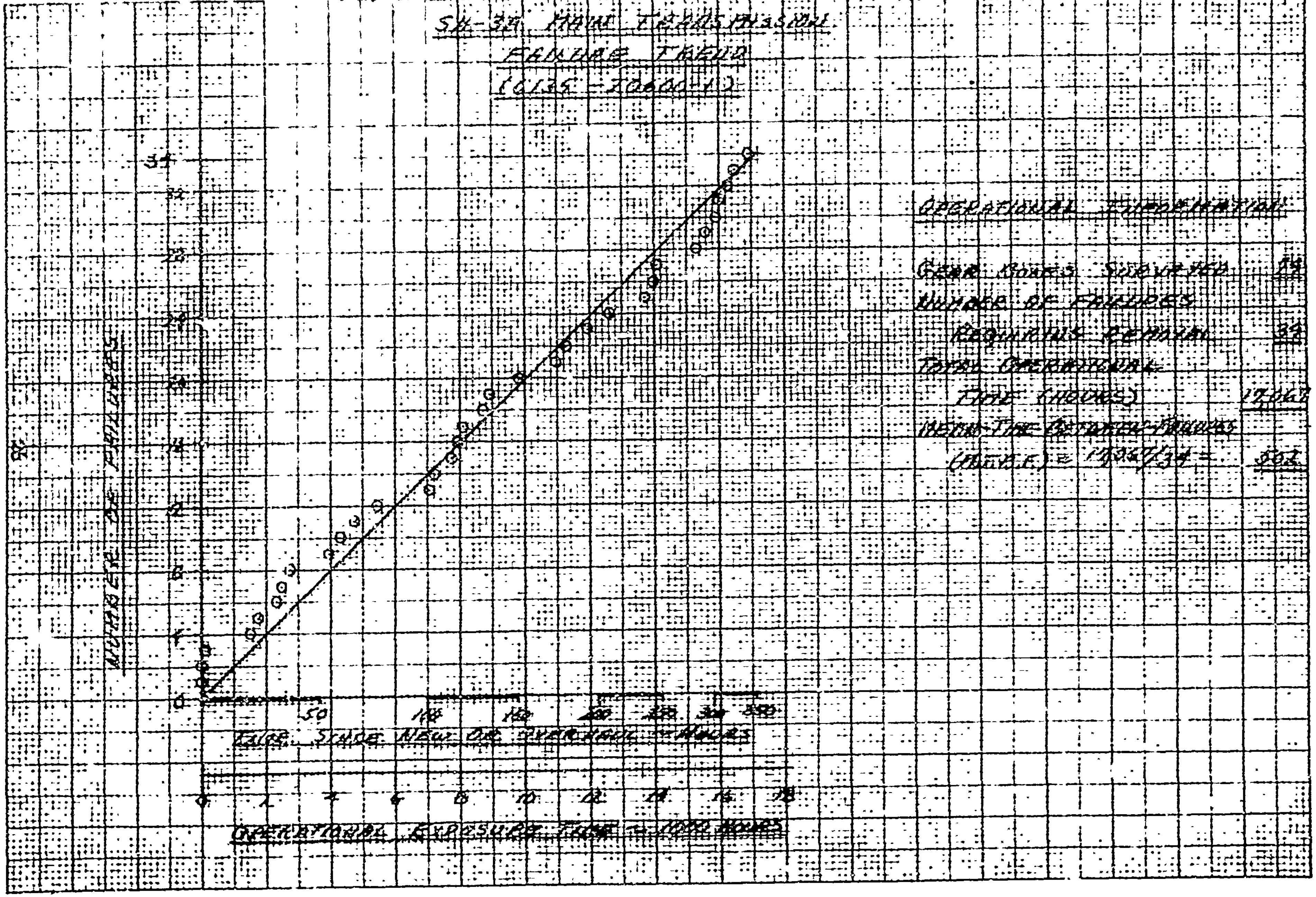
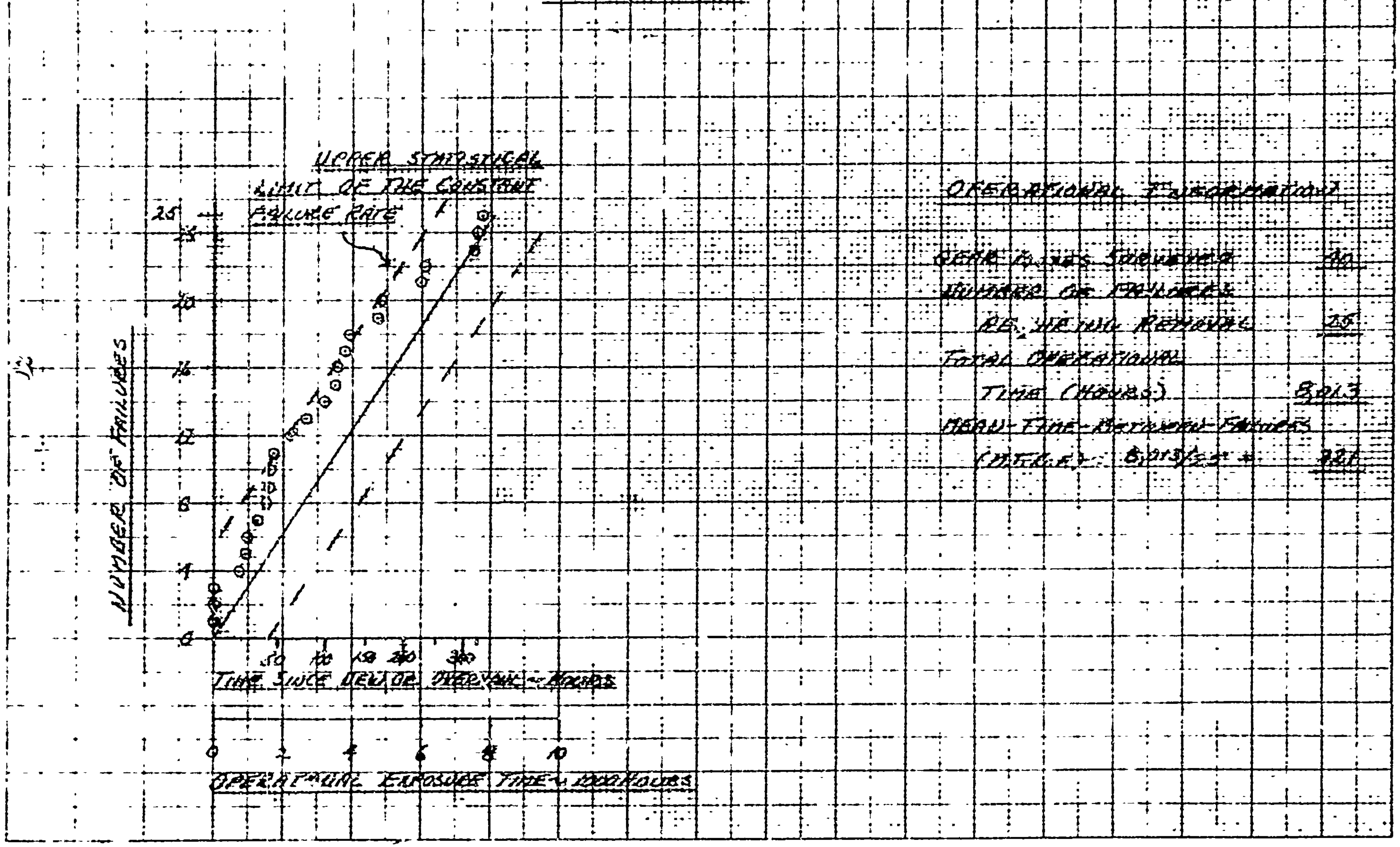


FIGURE 4

SH-3A MAIN TRANSMISSION
FAILURE TREND



failure rate. Time histories of these two failures are shown in the upper two diagrams of Figure (4a). The first curve illustrates that the preload problem was essentially a zero-time failure. The second shows that the snap-ring malfunction was an "infant mortality" (usually occurring within the first sixty hours of gearbox operation).

The lower diagram shows that the remaining failures of the gearbox exhibit a constant failure rate pattern. (MTBF = 321 hours)

- Figure (5) shows the failure data for the transmission incorporation improvements for the above problems, demonstrating that the unit again operates in the constant failure rate region. (MTBF = 510 hours)

- Figure (6) covers data on the S6135-21000-5 gearbox which was the next production version of the H-3 gearbox. This unit incorporated further design improvements lowering the failure rate (still constant). (MTBF = 546 hours)

Unfortunately, the service interval (TBO) of all the above gearboxes was held at 500 hours. Even though all but the S6135-20600-6 gearbox (Figure (4)) operated at constant failure rate and none experienced any catastrophic failures.

FIGURE 4(a)

SH-3A MAIN TRANSMISSION
TRENDS OF SIGNIFICANT MODES OF
FAILURE
(6135-20600-6)

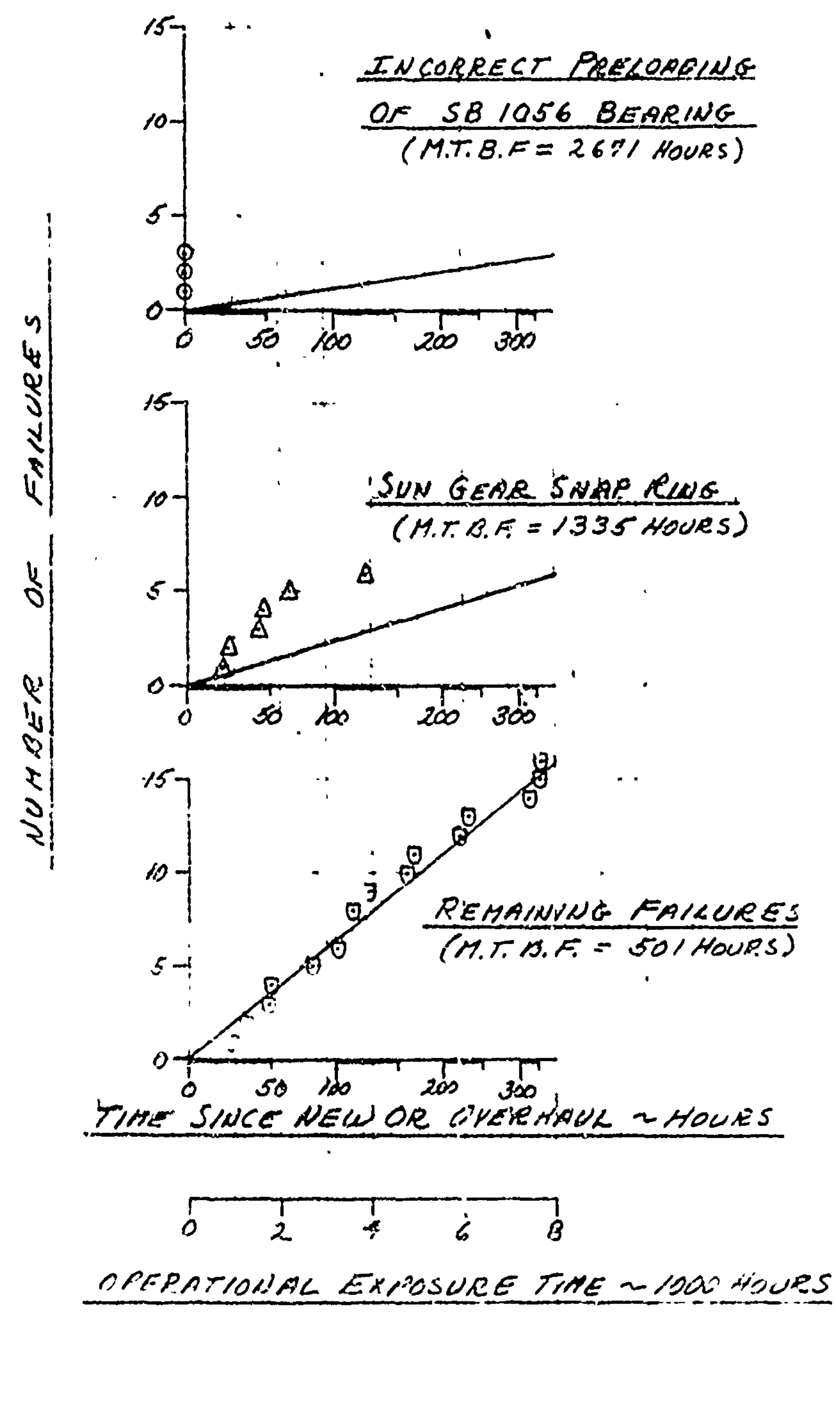
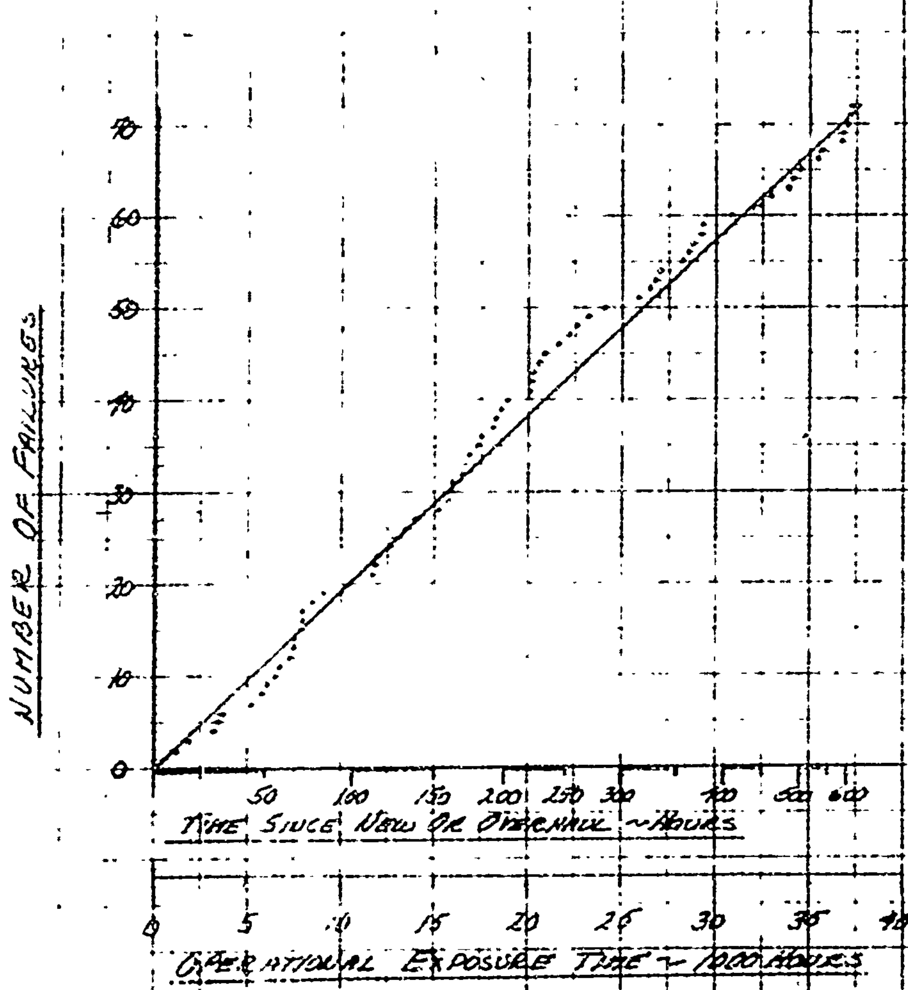


FIGURE 5.

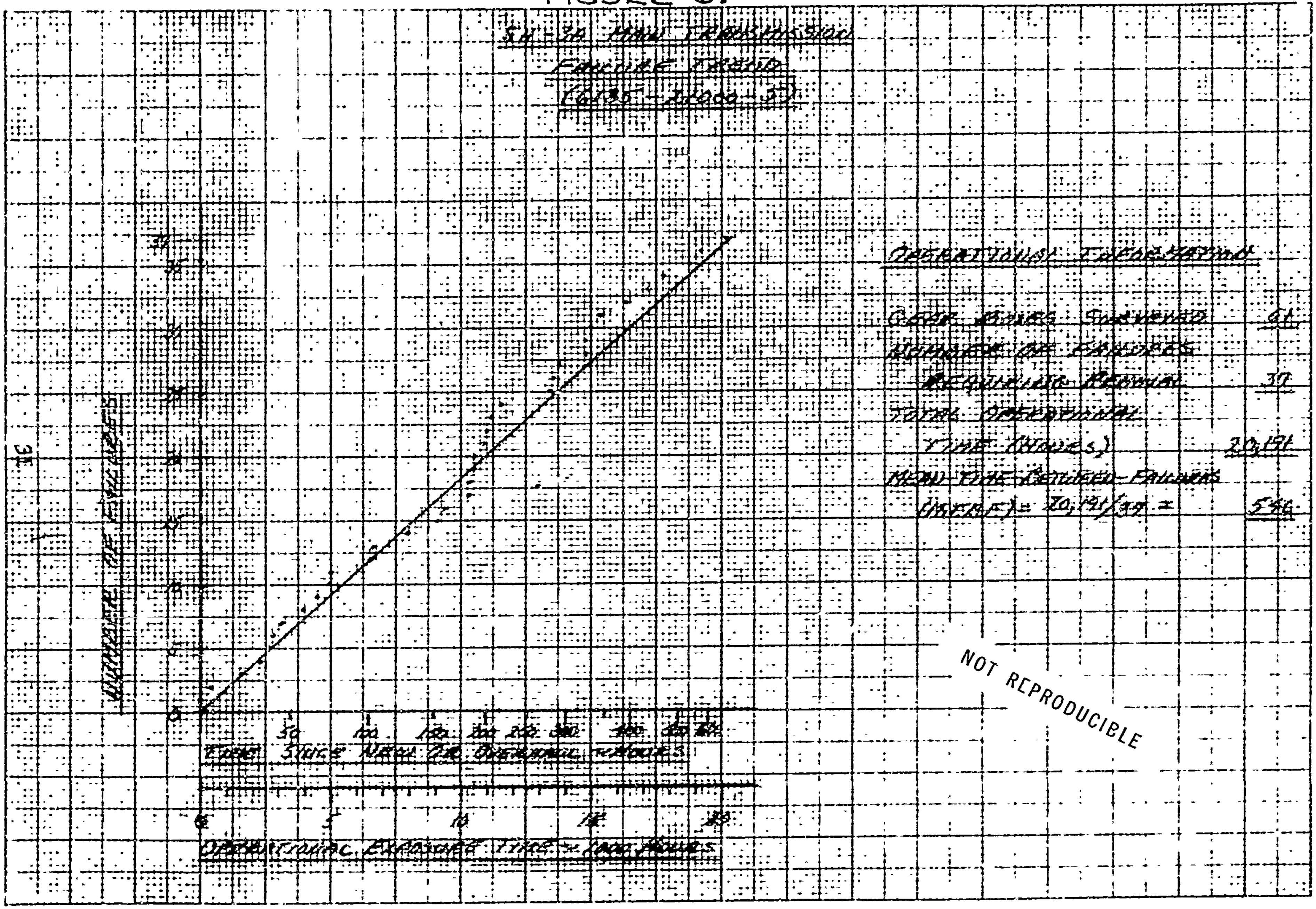
SH-3A MAIN TRANSMISSION
FAILURE TREND
(6135-2.[illegible]-2)



OPERATIONAL INFORMATION

GEAR BOXES SURVEYED	114
NUMBER OF FAILURES REQUIRING REMOVAL	72
TOTAL OPERATIONAL TIME (HOURS)	37,402
MEAN-TIME-BETWEEN-FAILURES (M.T.B.F.) = 37,402/72 =	510

FIGURE 6.



- Figure (7) shows failure trend data on a gearbox with a higher service interval and reflects a substantial amount of high time gearbox operation. This curve shows a "wear-out" pattern* or trend associated with an increasing failure rate of the driven bevel gear. The degree to which the driven bevel failure dominates the MTBF of this gearbox is shown in Figure (7a).

There were essentially no driven bevel gear failures in the first 125 hours of operation since new or overhaul, some failures before 400 hours and a rash of failures after 400 hours. Other less significant modes of failure also influenced this "wear-out" pattern. Figure (7b) shows the slight but noticeable influence of failures of the planetary pinion. (MTBF = 724 hours)

A similar review of the failure trends of the CH-3C, CH-53A and CH-54A was also made. It is significant to note that in the analysis of the service data accumulated on the main transmissions of these aircraft, no predominant modes of failure have been found.

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* The use of the term "wear-out" is that of the reliability engineer meaning region of increasing failure rate.

FIGURE 7.

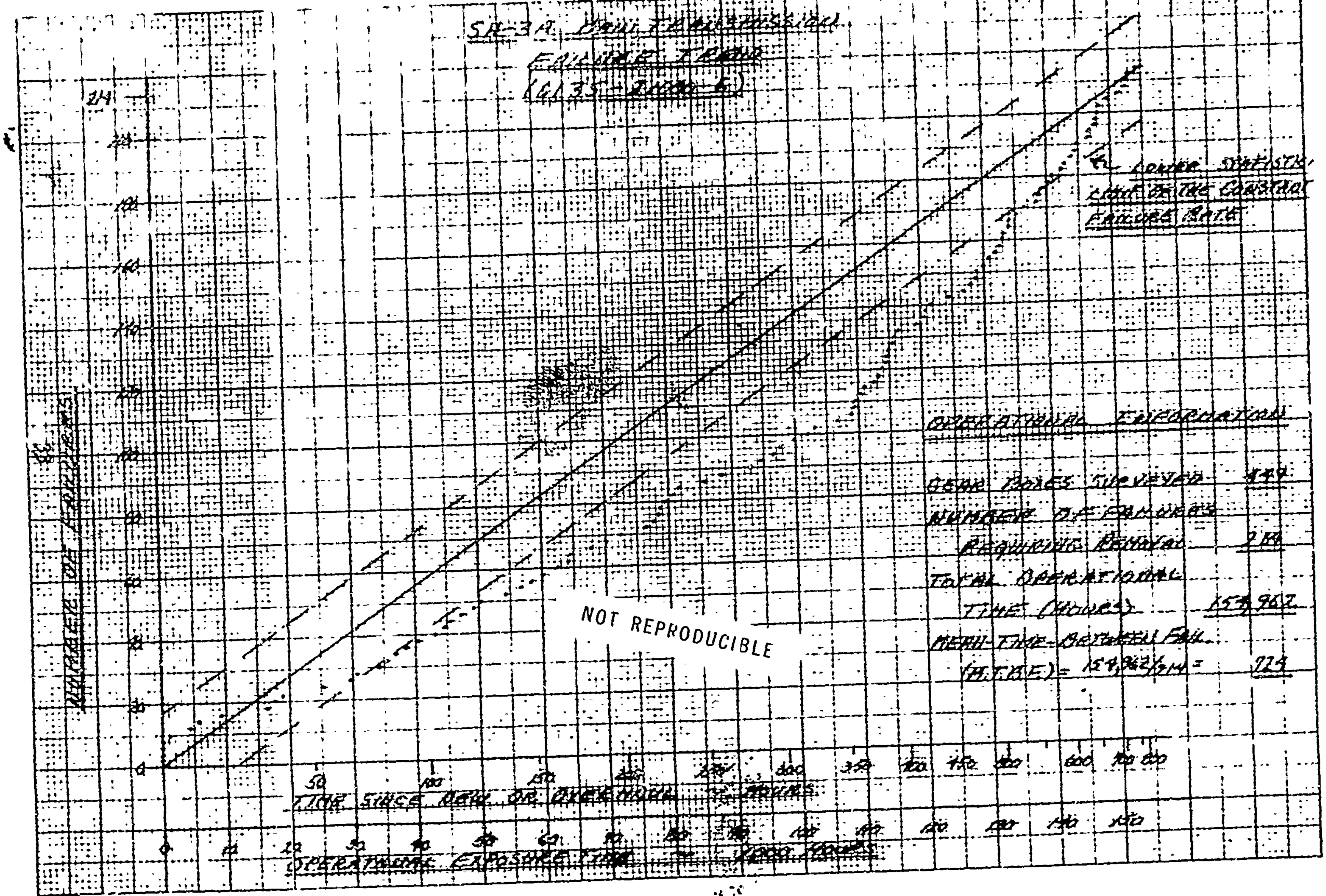

NOT REPRODUCIBLE
OPERATIONAL INFORMATION
TIME SINCE NEW OR OVERHAUL ~ HOURS
OPERATIONAL EXPOSURE TIME ~ 1000 HOURS

FIGURE 7a

SH-3A MAIN TRANSMISSION

FAILURE TREND OF THE DRIVEN BEVEL GEAR

(6135-21000-6)

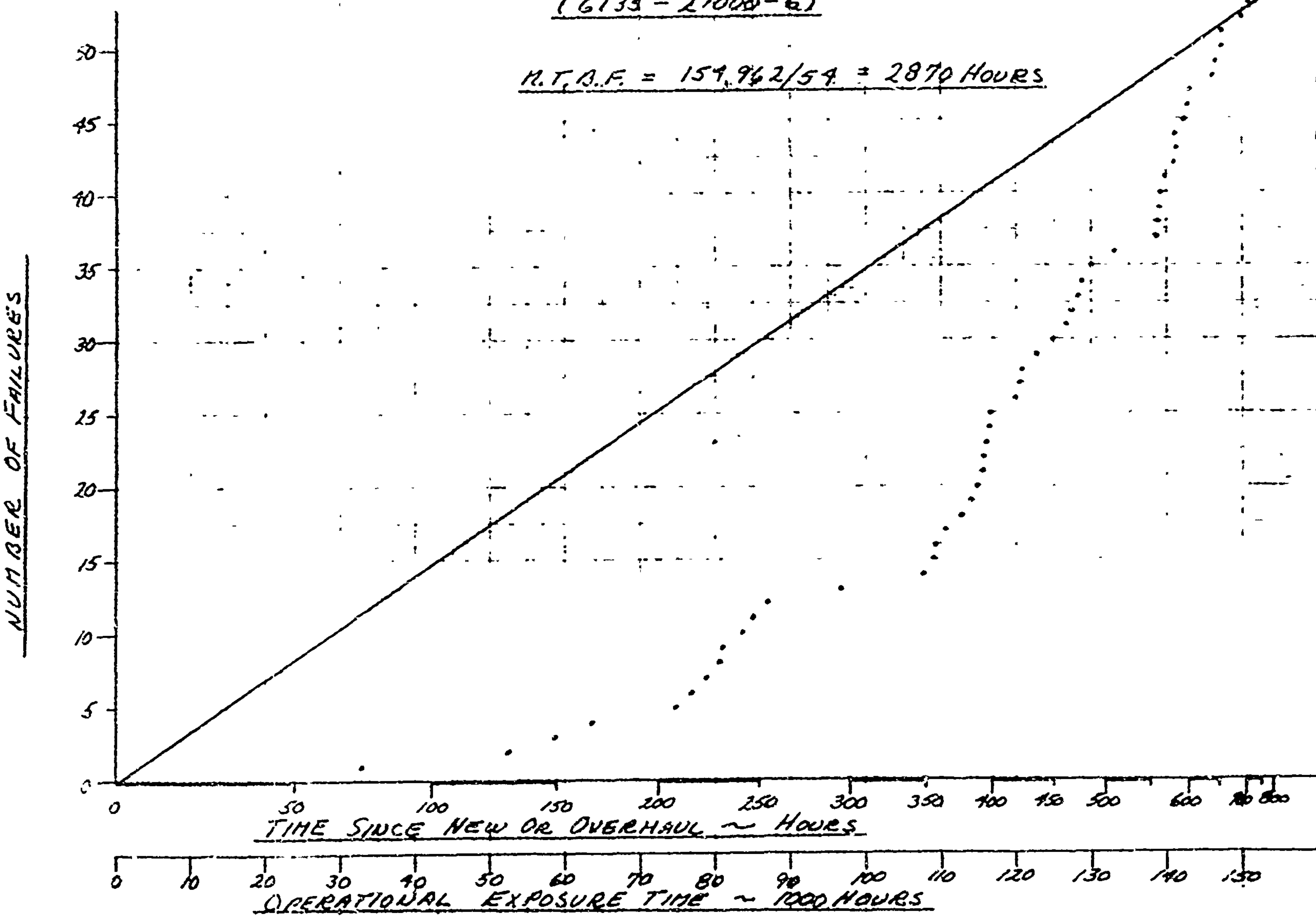


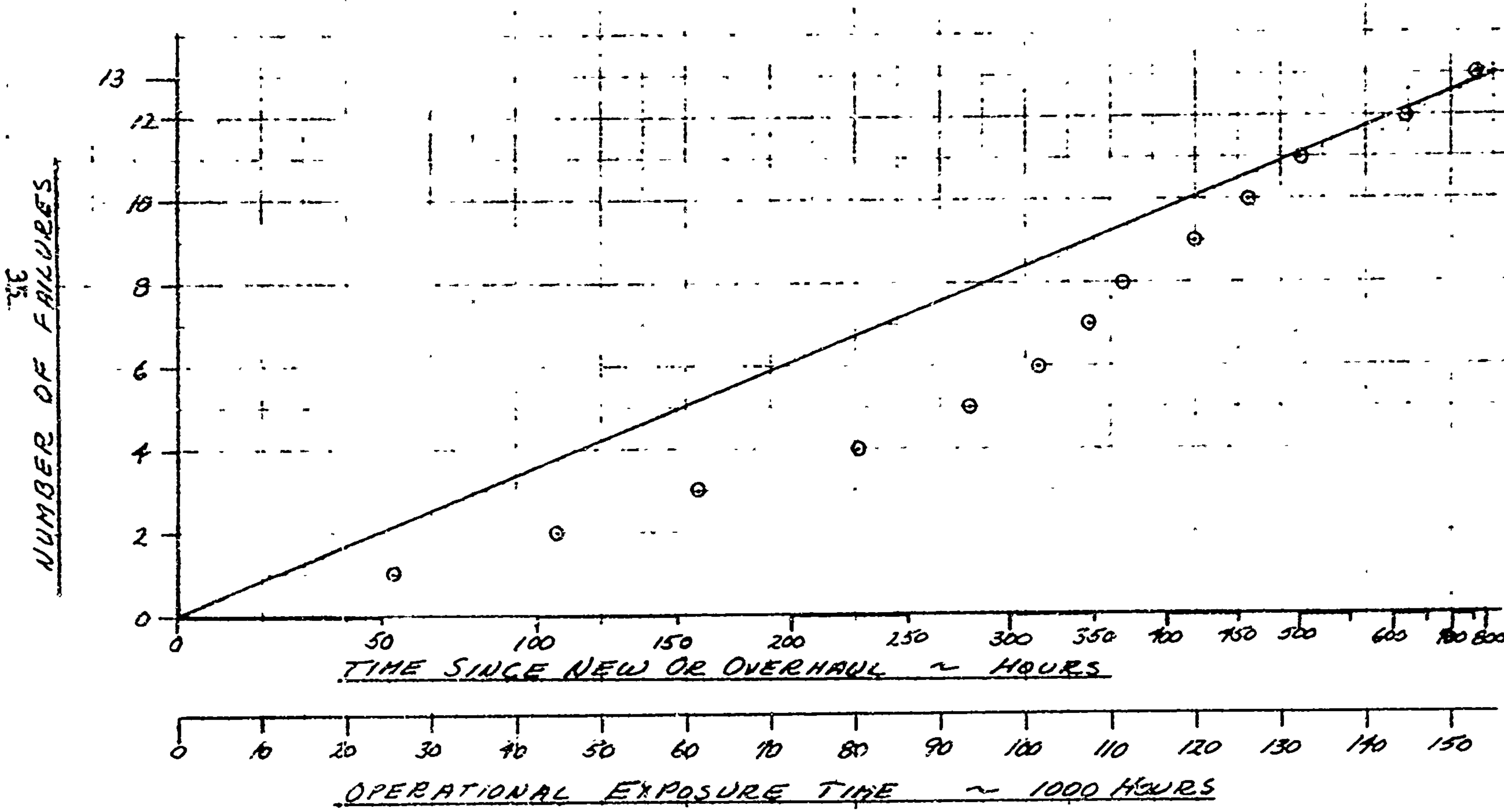
FIGURE 7(b)

SH-3A MAIN TRANSMISSION

FAILURE TREND OF THE PLANETARY GEAR

(6135-21000-6)

M.T.B.F. = 154,962/13 = 11,920 HOURS



- Figure (8) shows the failure rate (constant) for the U.S. Air Force CH-3C main gearbox.
(MTBF = 810 hours)

- Figure (9) is the failure trend of the CH-53A main gearbox. While some failures of the first stage planetary pinions have occurred recently, there have not been a sufficient number to indicate a trend for this component.
(MTBF = 949 hours)

- Figure (10) shows the failure rate of the main gearbox of the U.S. Army CH-54A. Most of the early removals were due to overtemperature problems and lubrication pump seizures. Improved gear shielding and the use of a higher viscosity oil (SATO 35) eliminated these problems.
(MTBF = 734 hours)

- Figures (11) and (12) give a chronological history of the MTBFs and MTBRs for two models of the H-3 aircraft. In these curves, pilot- and many maintenance-induced problems have been eliminated. The resulting MTBFs and MTBRs are therefore somewhat higher than presented in the previous curves in that they reflect only the material fracture, wear, spalling, etc., type of failure.

- Figure (11) shows the failure and removal history of the SH-3A and SH-3D main transmissions obtained from data gathered, averaged and plotted quarterly. The MTBF improvement noted at the end of 1963 was the result of successive gearbox refinements. The MTBF degradation

FIGURE 8.

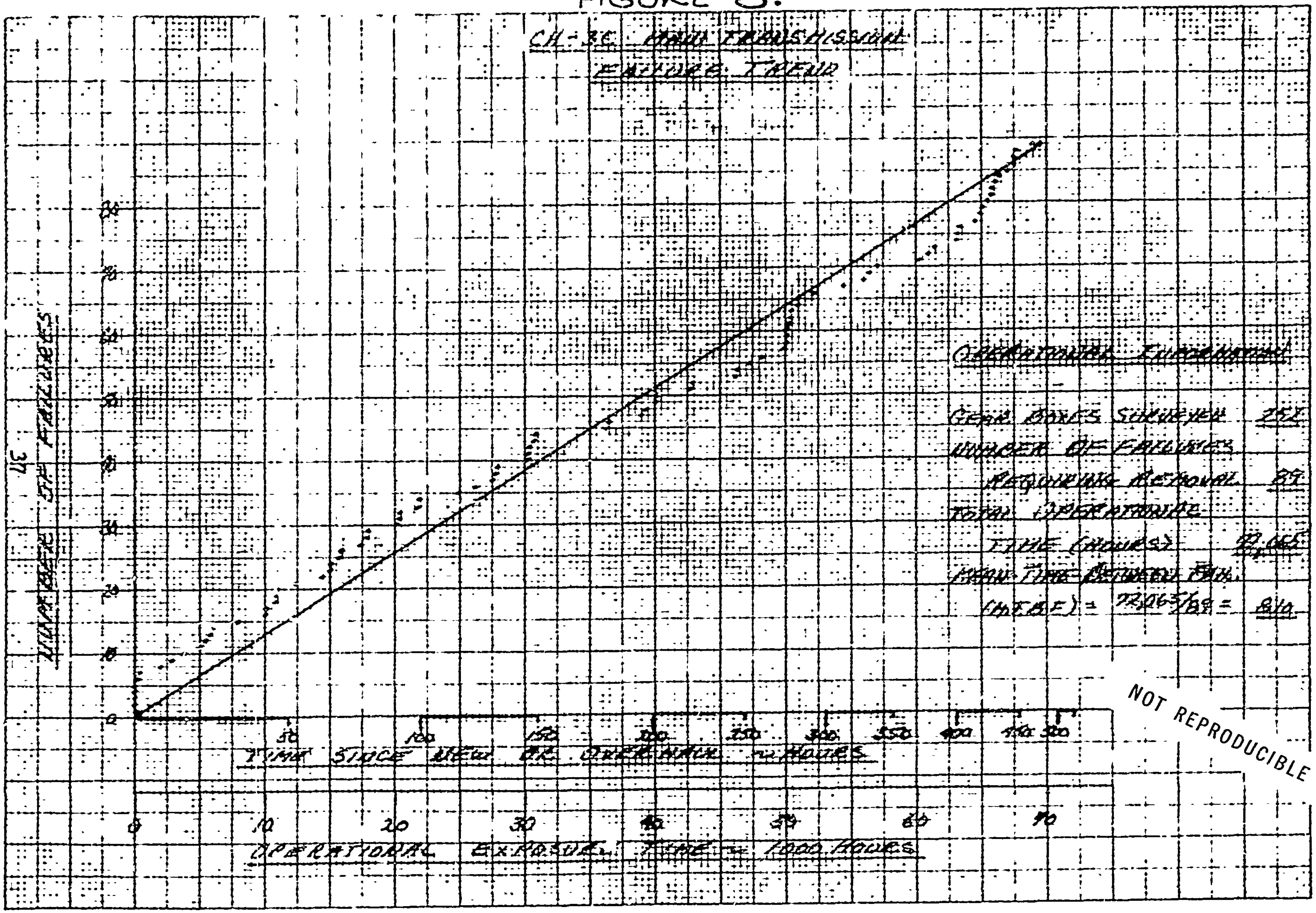

CH-3C MAIN TRANSMISSION
FAILURE TREND
NUMBER OF FAILURES
0
10
20
0
50
100
150
200
250
300
350
400
TIME SINCE NEW OR OVERHAUL ~ HOURS
0
10
20
30
40
50
60
70
OPERATIONAL EXPOSURE TIME ~ 1000 HOURS
OPERATIONAL EXPERIENCE
NUMBER OF FAILURES
REQUIRING REMOVAL
TOTAL OPERATING
TIME (HOURS)
MEAN TIME BETWEEN FAIL.
(MTBF) =

FIGURE 9

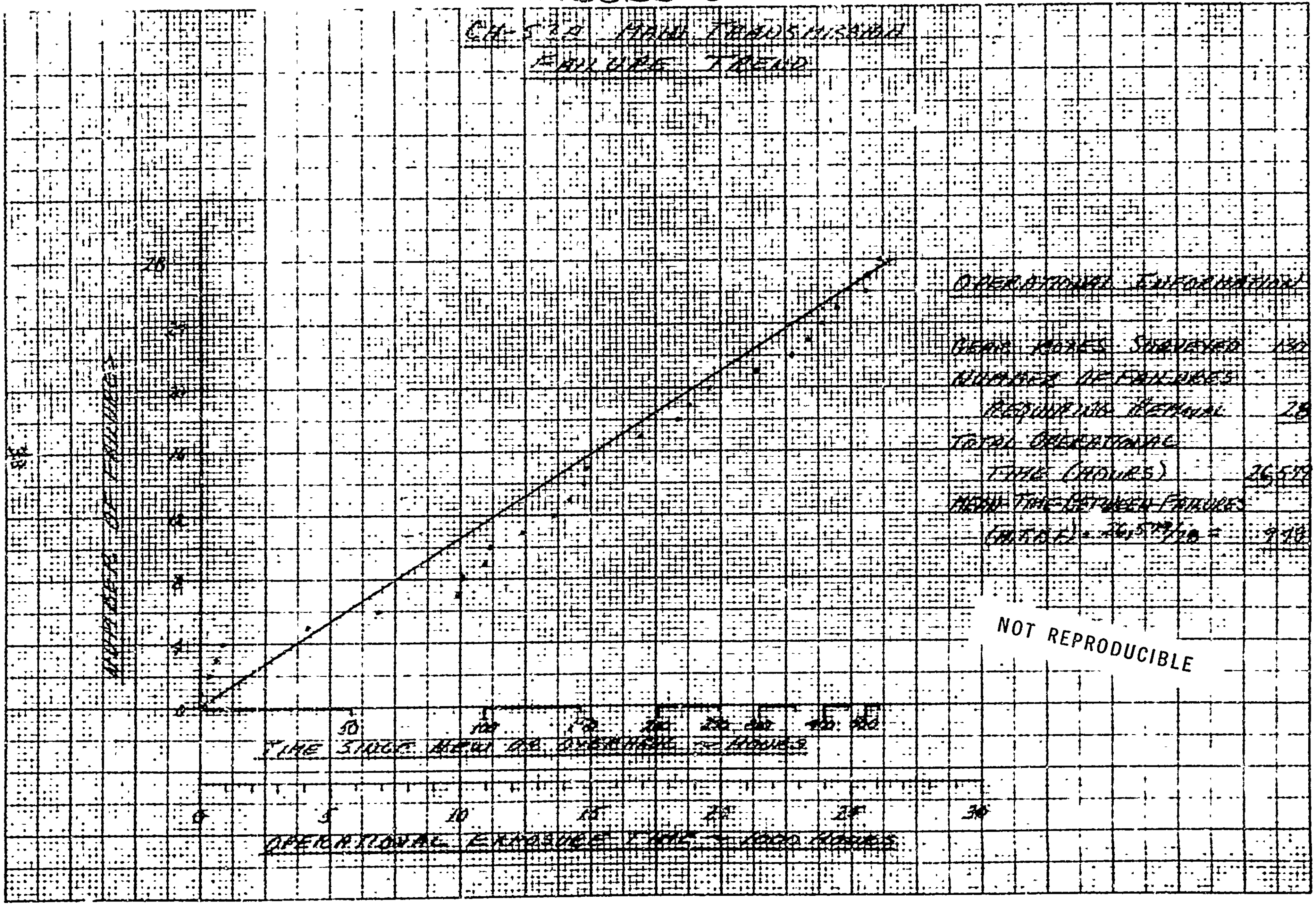
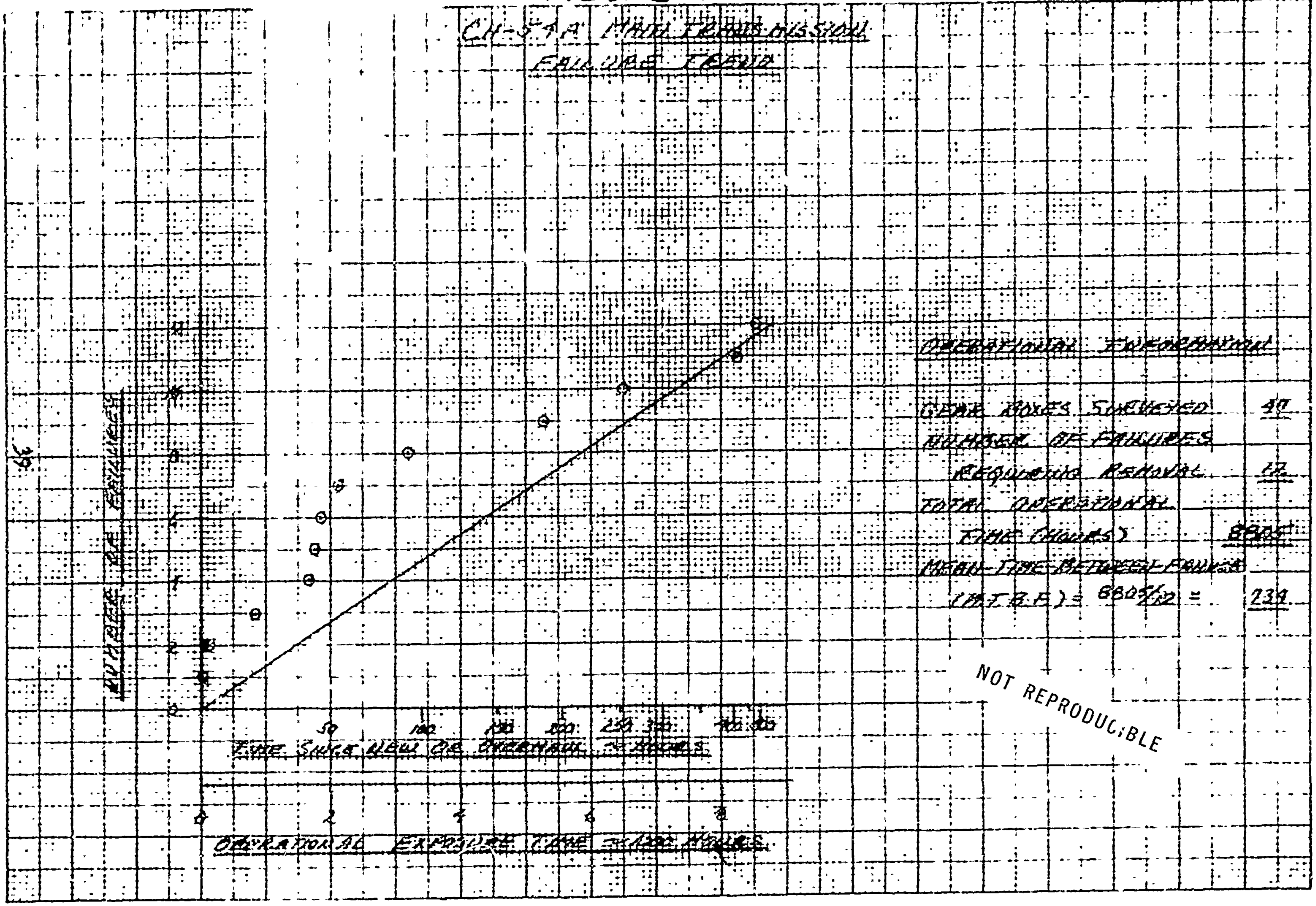
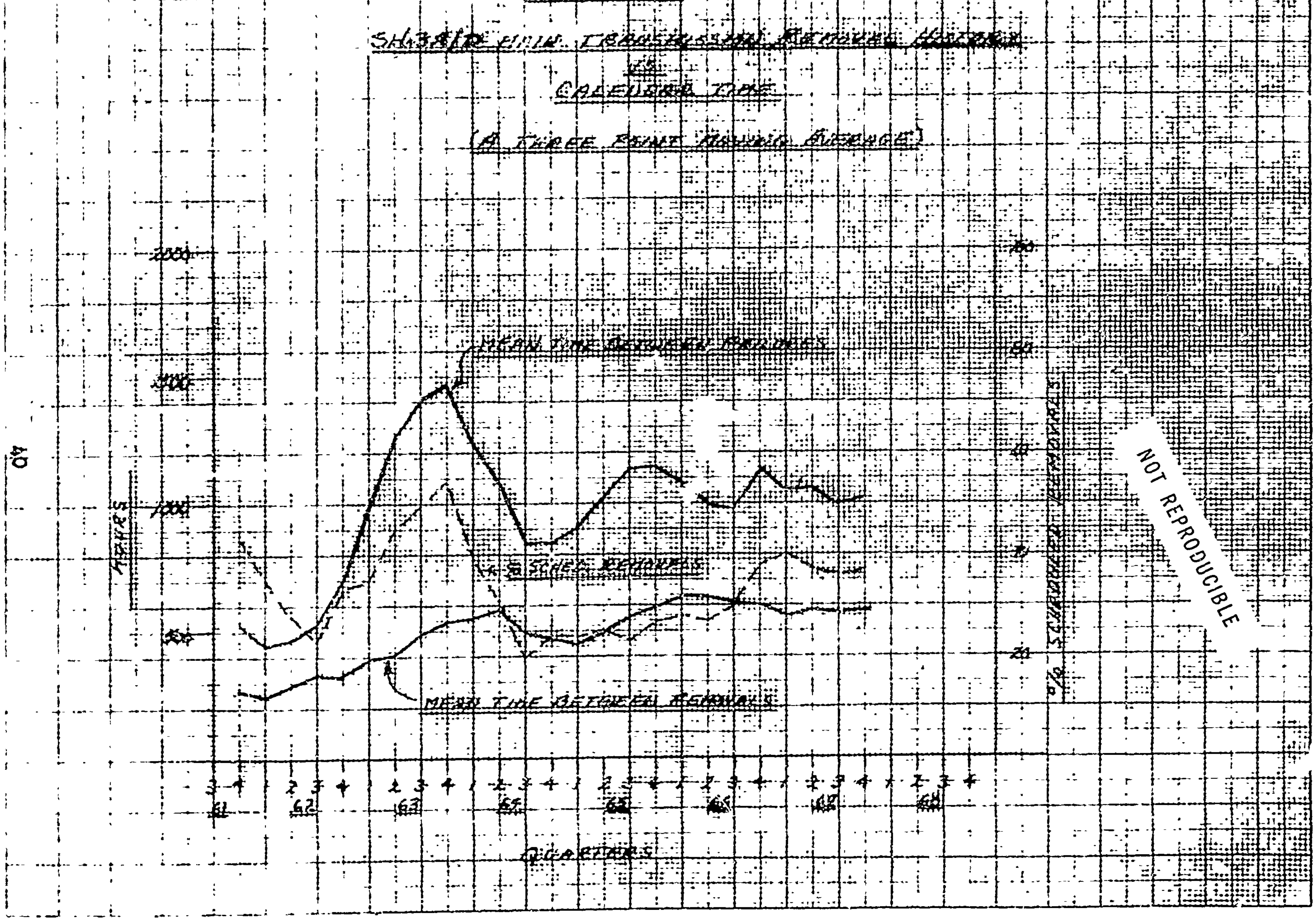

FAILURE TREND
OPERATIONAL INFORMATION
NUMBER OF FAILURES
TOTAL OPERATIONAL TIME (HOURS)
NUMBER OF FAILURES
TIME SINCE NEW OR OVERHAUL ~ HOURS
OPERATIONAL EXPOSURE TIME ~ 1000 HOURS

FIGURE 10.



CH-47A MAIN TRANSMISSION
FAILURE TREND
NUMBER OF FAILURES
TIME SINCE NEW OR OVERHAUL ~ HOURS
OPERATIONAL EXPOSURE TIME
OPERATIONAL INFORMATION
GEAR BOXES SURVEYED
NUMBER OF FAILURES
REQUIRING REMOVAL 12
TOTAL OPERATIONAL
TIME (HOURS)
MEAN TIME BETWEEN FAILURES
(M.T.B.F.) =
NOT REPRODUCIBLE

FIGURE 11


(A THREE POINT MOVING AVERAGE)
SCHED. REMOVALS
MEAN TIME BETWEEN REMOVALS
HOURS
2000
1500
1000
500
% SCHEDULED REMOVALS
100
80
60
40
20
61
62
63
64
65
66
67
68
QUARTERS

during 1964 was due to failures of the planetary pinion gear teeth caused primarily by the introduction of an engine with increased power capability. With the incorporation of further refinements and the incorporation of the "beefed-up" SH-3D transmission (larger bevel gears and planetary), the MTBF has improved and remained relatively stable.

- Figure (12) shows the chronological history of the CH-3C main gearbox MTBFs. The large degradation of the MTBF in 1966 and 1967 was due primarily to stripped threads in gearbox housings at lubrication fittings. The incorporation of steel inserts at all fitting locations (late 1967 - early 1968) has improved this situation. Several of the removals of this unit were based on exceeding arbitrarily established SOAP (Spectrographic Oil Analysis Program) levels. In nearly every case, no discrepancy was found in the gearbox on disassembly. A further discussion of Spectrographic Analysis is included in a later section.

REVIEW OF OVERHAUL EXPERIENCE

To evaluate the service interval (TBO) practices currently employed by the U.S. military organizations, a review of 324 DIR[1], DIS[2], and

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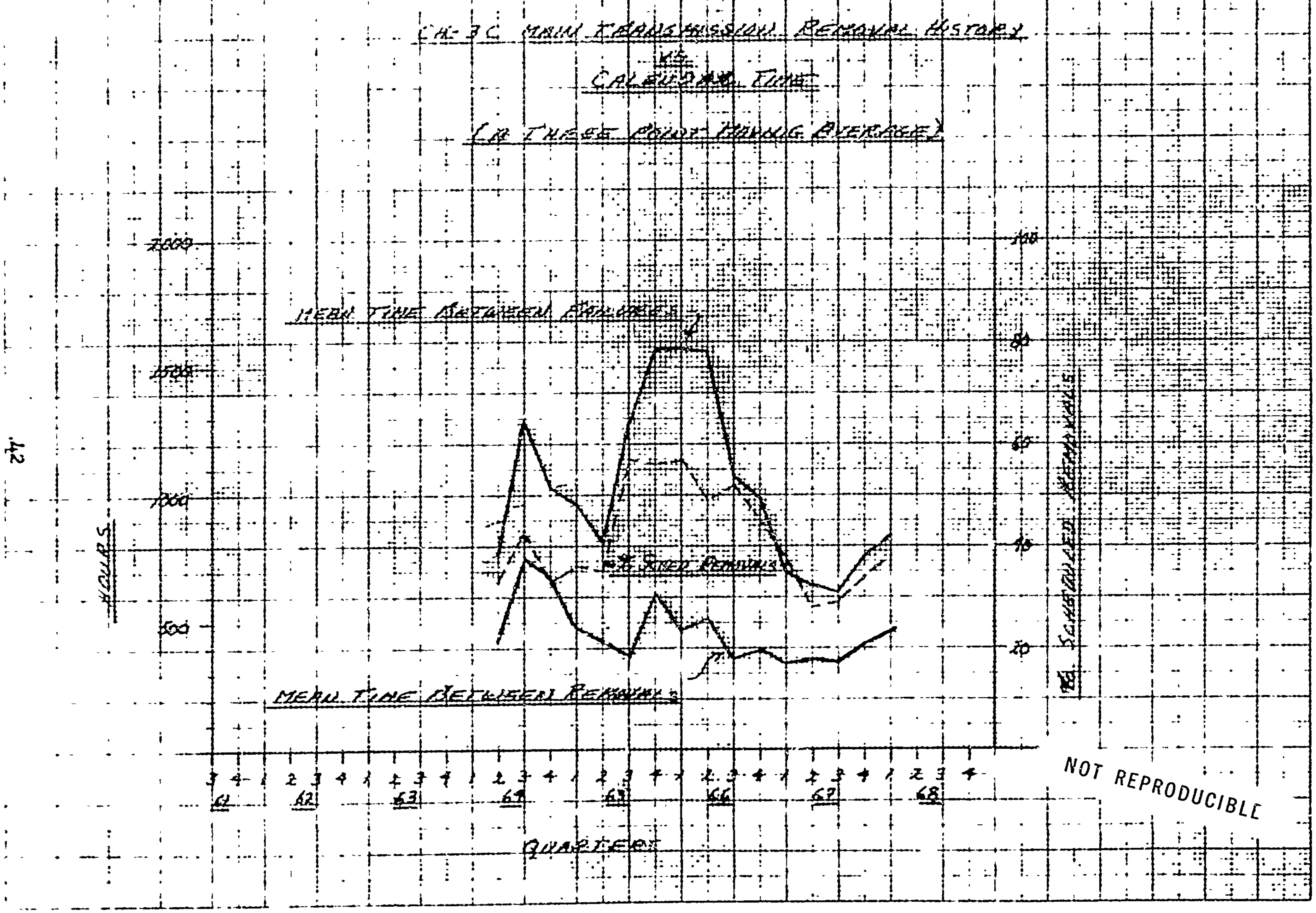
(1) DIR: Disassembly Inspection Reports, U.S. Navy

(2) DIS: Disassembly Inspection Summary, U.S. Army

FIGURE 12



CH-3C MAIN TRANSMISSION REMOVAL HISTORY
VS
CALENDAR TIME
(A THREE POINT MOVING AVERAGE)
MEAN TIME BETWEEN FAILURES
MEAN TIME BETWEEN REMOVALS
% SCHED REMOVALS
HOURS
2000
1500
1000
500
100
80
60
40
20
% SCHEDULED REMOVALS
3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
61
62
63
64
65
66
67
68
QUARTERS
NOT REPRODUCIBLE

and TDR[1] was made. All of these overhauls were performed at Sikorsky Aircraft under the supervision of Engineering personnel from the Transmission Design Group.

Of the 109 high time[2] gearboxes reviewed, less than ten had discrepancies that warranted removal from service. For the most part, the transmission could have remained in service for considerably longer intervals.

It is also interesting to note that on the CH-54A there have been several U.S. Army requests to extend the service interval of the main gearbox from the approved 500-hour TBO to 600 hours. None of these units were removed prior to reaching the extended service interval. Currently, there is a program to extend the transmission service interval to 800 hours. Of the five gearboxes being monitored, one was removed at 615 hours due to the lack of a repair part locally. Two units will be inspected at 700 hours and two at 800.

The U.S. Navy also extended the TBO for the SH-3A main transmission during a period of serious logistic problems with that unit due to tooth fractures of the driven bevel gear. Recognizing that the failures were detectable (chip detector) and noncatastrophic (prior to improved chip detector incorporation several were found at overhaul). The TBO's were extended from the recommended 500 hours to as high as 1,000 hours. In all, 29 units achieved the extended intervals without discrepancy. In no case did any of the units extended beyond the normal TBO experience a catastrophic failure.

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(1) TDR: Tear-Down Report, U.S. Air Force

(2) Completing approved overhaul interval

The approach to service intervals (TBO's) for helicopter transmission differs greatly between the individual military organisations and the commercial operator. Table IV below presents the user- (military and commercial) approved service intervals TBO(s) for the transmission system components for three versions of one Sikorsky helicopter. Also given are actual MTBR figures for each service. While there are some differences between the main gearboxes used for each user, the tail and intermediate gearboxes are substantially the same for all three applications.

TABLE IV

COMPARISON OF

SERVICE INTERVALS AND MTBRs

	USER A		USER B		USER C	
	TBO	MTBR	TBO	MTBR	TBO	MTBR
Main Gearbox	500	519	750	574	1200	885
Intermediate Gearbox	1000	1167	2000	2095	3000	N/A
Tail Gearbox	1000	1550	2000	2230	3000	N/A

All the gearboxes of Table IV were qualified/substantiated in the same (or similar) test programs. While admittedly there may be some differences in operating conditions, it is apparent that one of the operators is extremely conservative (and not cost effective) in his TBO practices.

While only a limited number of examples have been presented in this report (and considerably more are available), it is obvious that providing there are no known parts with replacement intervals (life-limited), if the component is operating satisfactorily - leave it alone.

Analysis

The relationship between MTBF, MTBR, TBO and Percent Scheduled Removals is shown in Table V for a transmission with a constant failure rate. It is hoped this presentation will clarify as well as provide a better understanding of these terms. This table shows how in the long run the MTBR and Percent Scheduled Removals is influenced by the reliability of the transmission (i.e., its MTBF) and by the usually somewhat arbitrary selection of TBO. It also demonstrates the effect on spares requirements of the TBO interval.

TABLE V

MTBR AND PERCENT SCHEDULED REMOVALS

vs

TBO AND MTBF

TIME BETWEEN SCHED. O'HAULS TBO	MTBF		
	500 HRS	800 HRS	1200 HRS
300 HRS	MTBR = 225 HRS % SCHED REM = 55	MTBR = 250 HRS % SCHED REM = 69	MTBR = 267 HRS % SCHED REM = 78
700 HRS	MTBR = 337 HRS % SCHED REM = 25	MTBR = 466 HRS % SCHED REM = 42	MTBR = 530 HRS % SCHED REM = 56
1200 HRS	MTBR = 455 HRS % SCHED REM = 9	MTBR = 662 HRS % SCHED REM = 22	MTBR = 760 HRS % SCHED REM = 37

Example: A transmission with a high reliability, MTBF = 1200 hours and a low service interval TBO = 300 hours has a high percentage of scheduled removals (78%) but a MTBR of 267 hours.

A transmission with a marginally acceptable reliability, MTBF = 500 hours and a 700-hour TBO has a considerably lower scheduled removal rate (25%) but a MTBR of 337 hours and will actually require less spares.

This analysis clearly demonstrates that achieving a high Percent Scheduled Removal is not necessarily a measure of transmission reliability. If a helicopter transmission has failure modes that are detectable (i.e., chip detector, pressure, temperature indications) and noncatastrophic in nature, "on condition" operation or a high TBO with only a small percentage of the units achieving a "high time removal" will result in the minimum number of spare transmissions for the program. Again, if the transmission component is operating satisfactorily - leave it alone.

OTHER AIRCRAFT

An earlier study,* conducted on other Sikorsky models including the H-34 and H-37 indicated similar advantages for (on-condition" operation of helicopter dynamic components. This investigation concluded that ".... With reliable in-flight detection devices and proper inspection techniques the "overhaul on condition" philosophy can be achieved with no increase in

* OVERHAUL ON CONDITION - ELIMINATE TIME BETWEEN OVERHAUL, by A. A. Coronato, Sikorsky Aircraft, American Helicopter Society Forum Proceedings, May 1961

risk to the operator. As a matter of fact, the reliability of the aircraft will be increased since it means less "tinkeritus" and reduces the hazard of improper installation or adjustments. In addition the integrity of components will be greater since they will be subject to less overhaul abuse and damage. The overall cost and the cost to the operator will be substantially reduced and greater availability of aircraft to perform mission requirements will be realized."

COMPARISON OF SERVICE AND TEST DATA

A comparison of the test data and service experience for the transmission components of the H-3 and H-53 was made to determine which of the initial test programs uncovered the service problems experienced on the early production transmissions. It is apparent from this review that indications of later service problems were nearly divided evenly between back-to-back and tie-down tests. Table VI shows the comparison. Data for CH-54A, although available, was omitted from this comparison since the only type of ground testing to the date of this report has been conducted on the H-54 Dynamic System Test Facility.*

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* Production acceptance testing on a U.S. Army-funded regenerative bench test stand was initiated in July 1968. This facility will be used for the development program on a growth H-54 transmission in early 1969.

TABLE VI

COMPARISON OF TEST AND SERVICE EXPERIENCE

H-3 AND H-53 MAIN TRANSMISSIONS

A/C	LEVEL OF FAILURE	PART	MODE(S) OF FAILURE	NUMBER OF FAILURES: TESTING				
				Back-to-Back	Turbine Test Bed	Tie-Down	Flight Test	Service Experien
		Sleeve Bearing	Seizure, Overlay Flaking	6	1	5		11
		Planet Pinion Bearing	Spalling of Raceways	9		6		4
		FWU Bearings	Spalling of Raceways	7	3	8		18
		Upper and Lower Main Shaft Bearings	Spalling	7		4		11
		Bevel Gears	Scuffing and Tooth Fracture	8	1	4		69
	MAJOR	Input Pinion, Timken Bearing	Fatigue Pitting	1		-		2
		Planet Gear	Scuffing and Tooth Fracture	2		-		11
		Helical Gear	Tooth Fracture and Multiple Fatigue Pits	3		1		0
H-3		Sun Gear	Multiple Fatigue Pits	3		3		3
		Spur Gear	Tooth Fracture	1		-		29
		Sun Gear Snap Ring	Dislodged					10
		Seal Housing Assembly	Stripped Lube Threads	1				31
		Nut - Lower Outer Shaft	Loss of Torque	1				0
		Main Gear Box Bearings	Handling Damage and Corrosion Stains	1				16
		F.W. Spring	Broken Piece	1				0
	MINOR	Cam Bushings	Wear	1				0
		Upper Bearing Support Nut	Safety Screw Sheared			1		0
		Solenoid Actuator	Static Fracture			1		1
		Rear Cover	Corrosion					5

TABLE VI - (continued)

A/C	LEVEL OF FAILURE	PART	MODE OF FAILURE	NUMBER OF FAILURES				
				TESTING				
				Back-to Back	Turbine Tested	Tie-Down	Flight Test	Service Experien
H-53	MAJOR	Planet Pinion Bearing	Spalling of Raceways	4	1	1		4
		FWU Bearing	Spalling and False Brinelling of Races	1	-	2	1	
		Upper and Lower Main Shaft Bearings	Race Spalling	-	2	3		
		Bevel Gear	None Recorded	-	-	-		
		Planet Gear	Scuffing and Tooth Fracture	-	-	-		4
		Sun Gear	Pitch Line Frosting	-	-	1		
		Gear Type Lube Pump	Fractured Teeth	1	-	3		
		Tacho-Gen Bearings	Spalled Races	2	-	-		
H-53	MINOR	TTO Pinion Bearing Lock Nut	Backed Off	2	2			2
		Planetary Thrust Washer	Wear		1			
		Thrust Bearing	Outer Race Misaligned at Manufacturing Split			1		
		Oil Screen	Bond Failure					1
		Oil Transfer Tube	Bucking Failure					2

COSTS

The lead time from initial design to service use often necessitates overlapping test and production fabrication phases resulting in components not thoroughly "debugged." While it is inevitable that this practice will of necessity continue, the most effective use of test funding should provide some improvement.

TEST COSTS

To provide some measure of the value of additional testing, the total program costs of the H-3 and H-53 helicopters were examined to determine the relative expenditures for transmission testing, production components, overhauls and modifications (ECP's). Figures (11) and (12) show these data.

It is interesting to note that for both programs only 6 to 7 per cent has been spent on all forms of main transmission development testing while ECP costs are estimated as 11 to 17 per cent of the overall transmission costs.

These comparative cost figures were established by taking the total number and cost of:

- production and spare main transmissions
- main transmission overhauls
- all approved main transmission ECP's
- main transmission test programs: tie-downs, dynamic system, and bench (The costs attributable to the main gearbox were established as for Figure (2).)

The cost data does not include the initial engineering design effort nor the cost of production tooling.

FIGURE 13.
H-3 TRANSMISSION COST

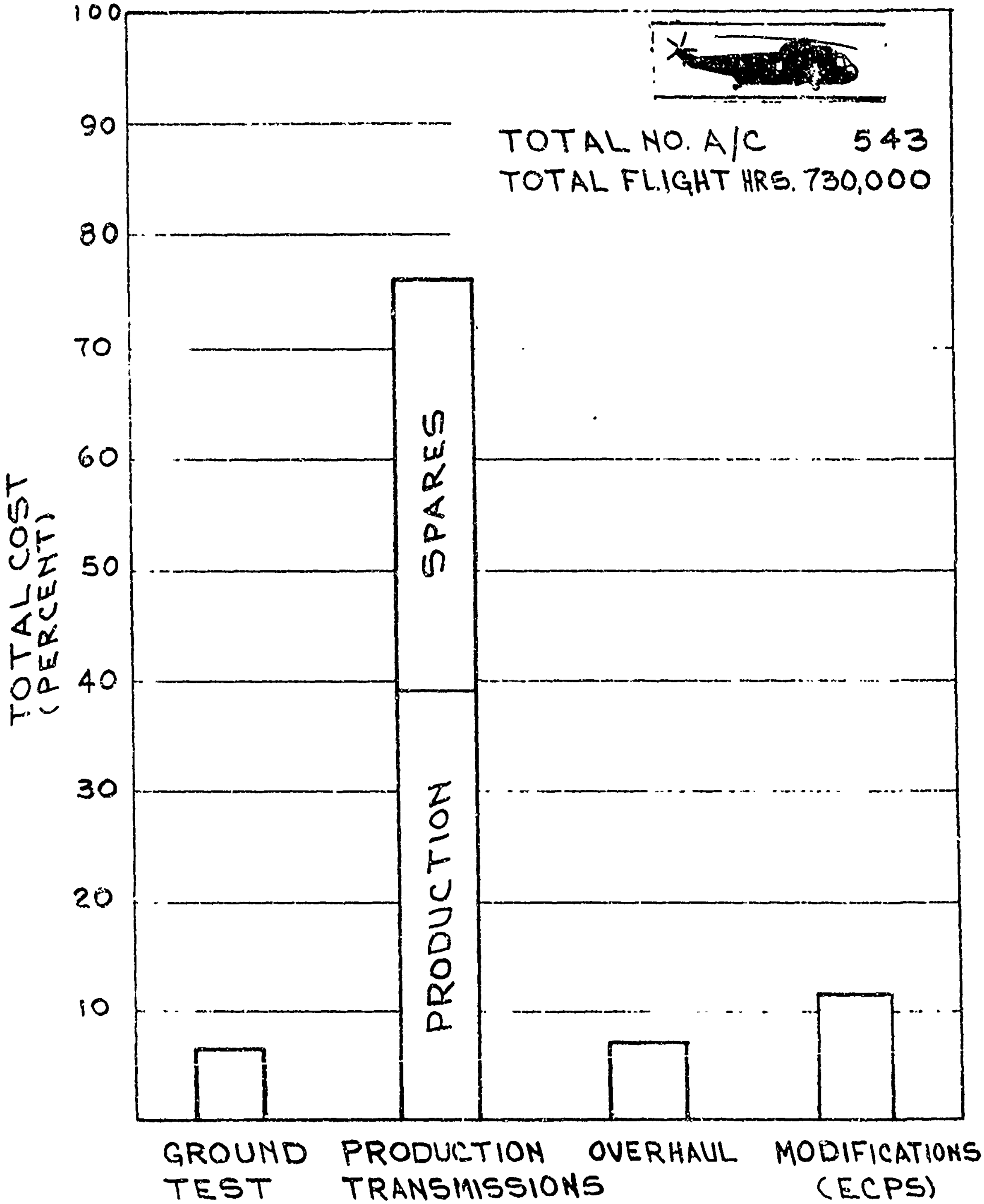
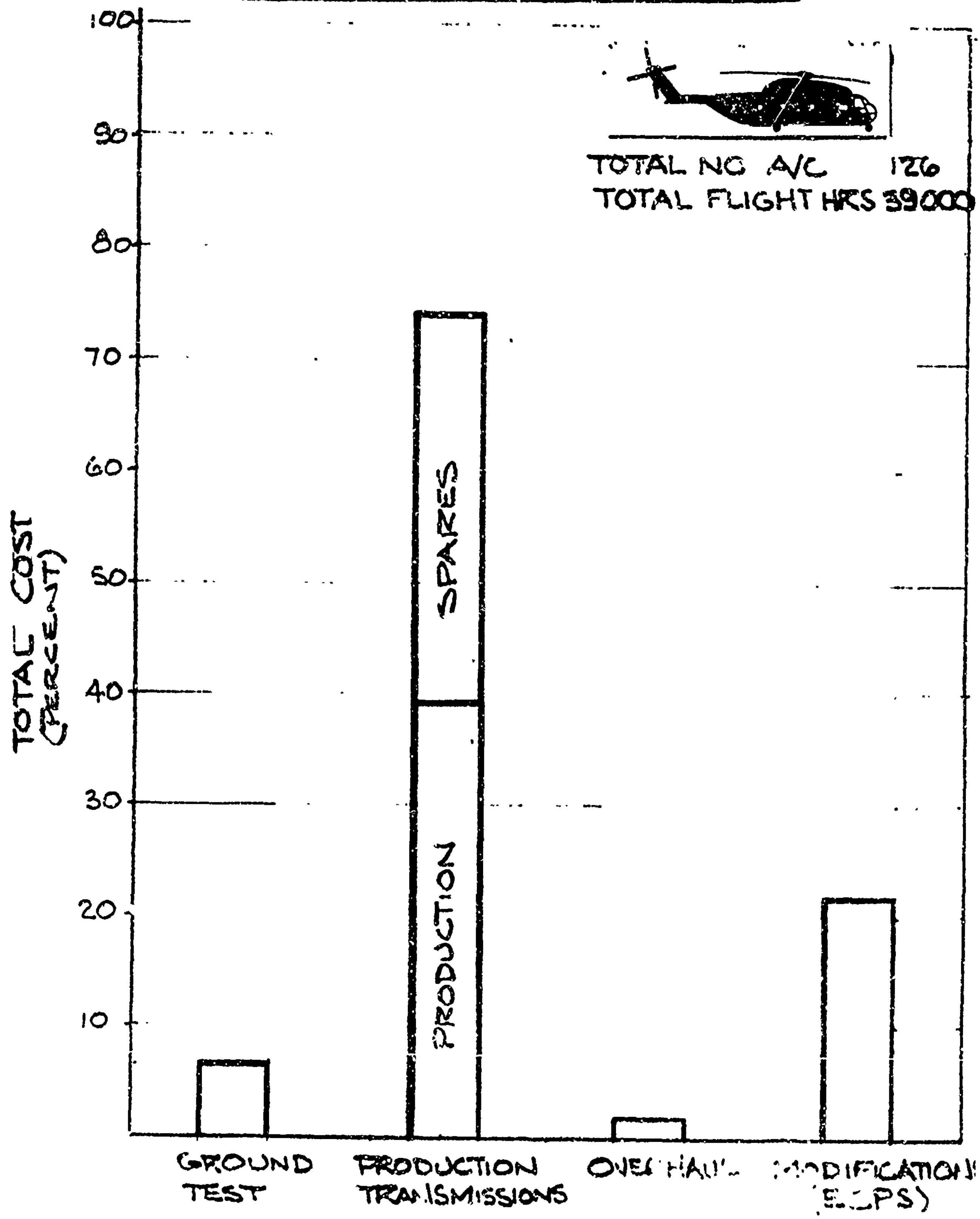


FIGURE 14
H-53 MAIN TRANSMISSION COSTS



EFFECT OF SERVICE INTERVAL ON PROGRAM COSTS

A recent study was conducted to determine the effect of service intervals (TBO's) on the overall program costs of the H-53 helicopter. The study considered the spares and maintenance support for the dynamic components of 120 aircraft over a seven-year (7) period.

This analysis indicated that the costs of spares, maintenance and overhaul for the transmission system components for TBO's of 800 hours and 2000 hours were approximately as follows. In the presentation of this analysis, the total costs of maintenance, spares and overhaul are given in thousands of dollars.

TABLE VII

TBO vs. MAINTENANCE, OVERHAUL AND SPARES COSTS
H-53 TRANSMISSION SYSTEM

TBO / COMPONENT	800 HOURS			2000 HOURS		
	Maint. Cost*	O'Haul Cost*	Spares Cost*	Maint. Cost*	O'Haul Cost*	Spares Cost*
Main Gearbox	75	5,300	12,500	30	2,100	5,700
Nose Gearboxes	26	1,720	3,400	11	680	1,500
Accessory Gearbox	6	470	1,050	3	260	700
Intermediate Gearbox	2	190	350	1	110	200
Tail Gearbox	10	530	950	6	310	600
SUBTOTALS	120	8,210	18,725	51	3,460	8,720
TOTAL	26,570			12,230		
PER CENT	100.0 PER CENT			46.5 PER CENT		

* Thousands of dollars

An increase in service interval from 800 hours to 2000 hours resulted in better than a 50 percent reduction in the spare components necessary at the same failure rate.

To demonstrate the capability of all of these H-53 drive train components* to operate for service intervals up to 2000 hours and at a higher power level, a 500-hour overstress bench test was proposed for each component. It is interesting to note that the cost of this program including all design effort, product improvement items, test gearboxes, spares, as well as all testing, is being conducted for less than 3 percent of the program support costs for the 800-hour components.

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* Main, left-hand and right-hand nose, accessory, intermediate and tail gearboxes

PROPOSED TRANSMISSION DEVELOPMENT PROGRAM

INTRODUCTION

For any new helicopter, the test program should be designed to provide for adequate development of the aircraft's dynamic components as well as to demonstrate that the design requirements (derived from the aircraft mission requirements) for safety, reliability, and maintainability have been met. The evaluation of the first two factors - safety and reliability - are of course the primary objectives of the test program.

DISCUSSION

To achieve a high degree of component reliability, the program must include provisions for making expeditious modifications to the test components as well as the initial production units (if production must be concurrent with prototype development - as it so often is). The ability to make modifications early in the program without lengthy evaluation and approval cycles (such is common with many of the current Engineering Change Proposal procedures) is as important to the overall goal - improved helicopter transmission reliability - as a properly designed and executed test program.

The early phases of transmission development testing should be directed toward uncovering the major modes of failure and demonstrating that the failures/malfunctions are non-catastrophic and fail safe and can be detected by the inspection and detection techniques to be used in service. This objective can be best accomplished by an "over-stress" bench test on the initial transmission(s), running the gearbox at the upper level of its

proposed operating spectrum (i.e. take-off rating or slightly above). It should be recognized that some portion of this test should be conducted at lower power levels to check lubrication, vibration, etc. as well as avoid scuffing and scoring of helical and bevel gearing. The operation of the gearbox(es) at powers well in excess of the normal operating schedule can produce results that are not meaningful. The load acceleration used in development (and qualification) tests should be kept within practical limits of deflection and stress. From past Sikorsky Aircraft experience, the practical maximum limits for acceleration of power, speed, thrust and load are approximately as follows:

Power	110% to 120% of take-off or maximum rating
Speed	110% of maximum speed
Thrust, Load	120% of maximum anticipated conditions

The operation of gearboxes at loads beyond these limits may produce excessive deflections. These components, therefore, may be operating beyond the point where the anticipated life-load relationships apply.

Gearboxes containing two primary drive systems, such as the rotor and propellor drive trains on compound helicopters, should be subjected to accelerated or "overstress" testing in each operational mode. Each test phase should include operation at or above the maximum rated power for each drive system. The duration of each test phase should be proportioned to anticipated ratio of service operation in each flight mode.

The use of several specimens to account for the many variables associated with part interfaces, strength, manufacturing tolerances etc. is very desirable. It is recognized that limitations in cost, lead time, scheduling and test facilities will not permit a sufficient number specimen to satisfy all reliability engineers, but the inclusion of several specimens in the development test phase will aid greatly in uncovering the major problem areas. The development testing of two to four transmission units is recommended. While it may be impractical to conduct development tests on more than one or two units prior to field deployment,

immediate follow-on product improvement programs on updated transmissions can result in appreciable savings in overall program costs <u>if initiated early enough in the program</u>. Such follow-on transmission programs can, for the most part, be conducted on bench test rigs without the need for additional tie-down or flight tests.

While much attention has been given to the regenerative test as a transmission development tool, it is not the intent of this report to belittle the advantages or necessity for dynamic systems, tie-down or flight testing. These test programs are often essential in examining the interface problems between engines, transmissions, rotors controls and airframe system. Many vibration, cooling, lubrication and operational problems cannot be solved without one or more of these other tests.

Summary

In summary, for any helicopter model, the initial and follow-on test programs should be prepared with the objective being to demonstrate that the design requirements for safety, reliability, and maintainability are met.

The essential methods to be employed in the test program to meet this objective are:

1. The use of the multi-level concept and the use of multiple specimens to account for the variabilities associated with interfaces, strength, manufacturing, and environments.

2. The use of overstress mode-of-failure testing to:

   a. Uncover modes of failure early and to demonstrate that they ar non-catastrophic and fail-safe by the inspection and detection techniques used in service.

   b. Verify "fixes" quickly

3. The conduction of accelerated qualification test(s) to reasonably verify that the design objectives are met.

4. The establishment of logical test scheduling such that there is a high probability that the transmission(s) will be free of major problems before entering subsequent, higher levels of testing with the ultimate goal of reasonably verifying that the design requirements for reliability and maintainability have been achieved by the time aircraft are deployed.

SUGGESTED TEST PROGRAM

The following paragraphs outline a suggested development (and qualification) test program for helicopter transmission system components. This program may be somewhat idealized and may require "tailoring" to suit the requirements of a particular helicopter program. It will, however, provide a guide for establishing developmental and qualification requirements for transmissions for future U.S. Army helicopters as well as provide adequate demonstration of proposed modifications to current aircraft.

Transmission Bench Tests

A minimum of two (2) test gearboxes should be subjected to the bench tests generally described in the following paragraphs. A test time accumulation of 50 hours on one gearbox should be completed prior to start of a Propulsion System Test (or Tie-Down Test).

1. A 200 hour overstress development test with 75% of the test time being at Take-off Power* or equivalent, 15% of the time at 110% of Take-off Power and the remaining 10% at normal cruise power. All other test time at powers required for cooling, etc. between take-off or better power increments should not be credited toward the total 200 hours.

   The test objective is to determine the modes of failure, detectability of failures, extent of fail-safe features. In addition the program should be used for the incorporation and evaluation fixes and in general to "de-bug" the transmission. The requirement is not to "pass" this test but to evaluate the design and compare its performance to the design requirements.

---

* The power levels indicated for the bench tests refer to transmission ratings. These ratings are not necessarily the same as the engine ratings for the aircraft.

2. Upon completion of the initial 200 hour overstress development test (or major malfunction of the test box) another 200 hour overstress bench test should be conducted on a second gearbox which incorporates all modifications suggested by the initial test. (The fabrication of "fixes" and improved items should be initiated while the first test program is in progress.

   The test spectrum for the second gearbox test should be essentially the same as the initial test.

3. A 500 hour endurance test with a minimum of 25% of the test time at take off power with the remaining 75% at the most severe mission spectrum with an acceleration factor of 1.25 minimum on all loads i.e. input shaft, take-off shafts, thrust, etc. The test objective is to demonstrate that the design objectives of reliability are met.

   Many of the component parts of the initial test gearbox could be utilized for the 500 hour endurance tests. New gears, bearings and the latest design of improved parts should be installed however.

Propulsion System/Tie-Down Test

The total propulsion system including all gearboxes, engine(s), shafting, rotor brake, clutches, accessories and controls should be subjected to the following tests as a minimum using either a test bed or the complete tied down helicopter. A test time accumulation of 20 hours should

be required prior to first flight of the aircraft and a test time/flight time ratio established at 2/1 for the test program to ensure an adequate test margin of time accumulation on components and systems.

1. A shake down test of 50 hours with 50% of the test time at take-off power, 10% of the time at 110% of take off power and the remaining 40% at normal rated power. The test would be divided into 5 ten hour cycles with one cycle being at 120% of normal rated speed and four cycles at normal speed ranges.

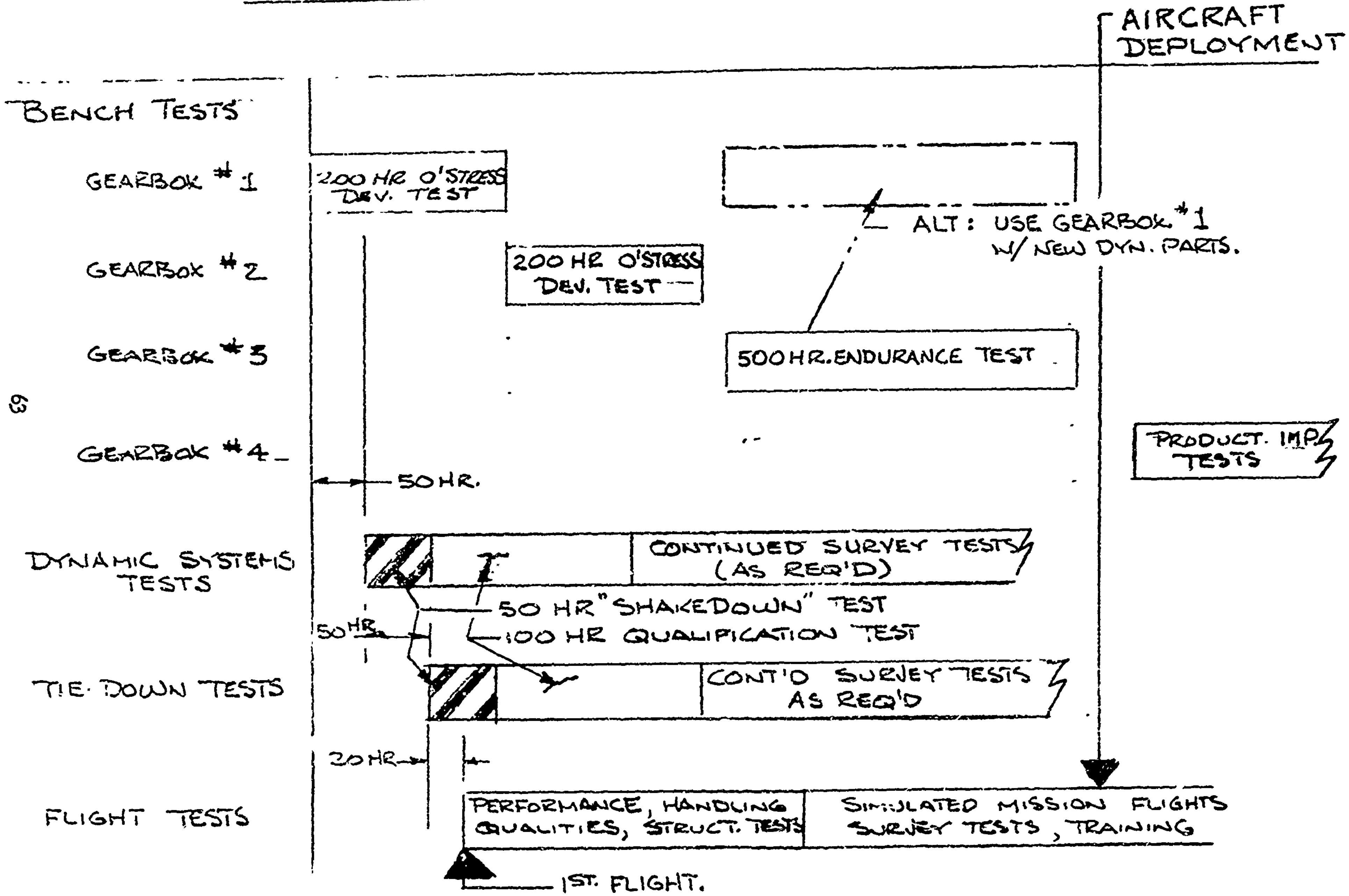
   The objective of this test is to demonstrate that the helicopter propulsion system is safe for flight. The requirement is not to pass this test but to demonstrate lack of catastrophic failure modes and the fail-safe features of the dynamic components, to satisfactorily demonstrate fixes for each mode of failure or major malfunction.

2. A 100 hour qualification test at the same spectrum as the 50 hour shake down test consisting of ten, 10 hour cycles with two cycles at 120% of normal rated speed and eight cycles at normal speed ranges.

   The objective of this test is to demonstrate the adequacy of the modifications developed for earlier problems encountered during the 50 hour shake down test and flight test and to assure reasonable operating intervals without failures. The requirement is not to "pass" this test, but

PROPOSED TEST PROGRAM

HELICOPTER TRANSMISSION DEVELOPMENT



to obtain a minimum of fifty test hours without failure or major malfunction on all parts scheduled for production.

Flight Test

The helicopter flight test program should be designed to complete the contractors and contractural aircraft handling qualities, performance and structural buildup programs in a minimum number of flight hours and in the shortest possible calendar time. In addition to the necessary survey test flights (stress, vibration, etc.) training and classical procedures of flying at incremental changes in air speed, CGs, a portion of the flight test program should be devoted to flying simulated missions.

Data obtained from these tests can be used to verify the design mission spectrum and to verify the operation and maintainability of the dynamic and airframe components under conditions approaching actual service operation.

Follow-on Product Improvement Tests

Upon completion of the ground test program, including the development and endurance bench tests, tie-down or dynamic systems tests, a product improvement plan for the transmission system components should be made. Follow-on bench testing to cover the evaluation of components manufactured by alternate fabrication sources,* additional improvements indicated by field experience, and planned transmission growth (power capability) should be initiated as soon as possible.

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* Some evaluation of alternate sources can be accomplished (if sources available) in the second development or endurance test.

In (a) follow on program(s) a new transmission incorporating the latest design features should be utilized for this test. A 200 hour test similar to the overstress development bench test should be conducted.

APPENDIX I

DEFINITION OF TERMINOLOGY

INTRODUCTION

There have often been major semantic problems in both industry and government with the terminology used in the description of life, operation, and reliability of aircraft dynamic components. The following definitions are proposed for many of these terms. Also included are comments on the terms and their definitions.

DEFINITIONS

SAFETY

Definition: Safety refers to prevention of loss of life, serious injury or loss of aircraft.

Comments: The specified level of safety determines reliability requirements from which other disciplines of design, test, produce, operate and maintain are derived. Arbitrary specification requirements for particular "service lives" or "must pass" tests prohibit the designer from selecting the best method he chooses to satisfy the prime requirement: safety. For example, a designer may choose to design a particular component for a high reliability, in which case the probability of failure is remote, or he may provide detection devices that give adequate warning time which achieves a better level of reliability.

DEFINITIONS

FAILURE

Definition: Failure is the "nonperformance" of a requirement expected of a component or system.

Comments: The requirement for a structure is that it performs the function of carrying loads. Therefore, if a structure has failed, it can no longer carry a load. Note that fracture, cracking, deterioration or damage does not necessarily constitute a failure.

FAIL SAFE

Definition: A fail safe device or structure has characteristics such that in the presence of abnormalities, such as fatigue cracking and/or physical damage or deterioration, the probability of a catastrophic failure prior to detection of the abnormality is extremely remote.

Comments: The term "fail safe" is an unfortunate choice of words. Only when a portion of a structure has "failed" and the remaining structure withstands the loading without failure can we have a "fail safe" structure.

SAFE LIFE

Definition: A finite life assigned to components subjected to fatigue or wear-out damage wherein the population of components presumably operates in service up to this established "life" without exhibiting evidence of failure.

DEFINITIONS

Comments: This concept has one fallacy: The procedure supposes a finite life, ignoring the statistical nature of things and is akin to predicting the life of a particular human being.

ON-CONDITION OPERATION

Definition: Removal of a component from service for overhaul dependent only on the component's serviceability, as determined by inspection.

Comments: Requirements for overhaul on-condition:

1.) The component is fail-safe.

2.) Abnormalities are detected in sufficient time to remove the component before internal damage causes high overhaul costs.

3.) Detection systems are such that components are not prematurely removed from service.

TIME BETWEEN OVERHAUL - TBO

Definition: TBO is the authorized time interval during which a component is allowed to operate in service prior to overhaul.

Comments: The establishment of a TBO places unnecessary hardships on the operator from the standpoint of aircraft availability and high cost of overhaul. A system composed of many components, such as a complex transmission, demonstrates a constant hazard failure rate. The act

of overhauling lowers reliability by reintroducing the component to the infant mortality cycle. The problem is much like that associated with any equipment: If it works, <u>leave it alone</u>.

<u>PREMATURE REMOVAL</u>

<u>Definition</u>: Removal of a component at less than the prescribed TBO for causes such as failure, suspicion of failure, or an incipient failure.

<u>Comments</u>: Is usual and normal.

<u>FATIGUE LIFE</u>

<u>Definition</u>: Commonly a calculated life below which no part will fail.

<u>Comments</u>: Same comments as "Safe Life."

<u>ISOLATED CASE</u>

<u>Definition</u>: The first instance of failure of a component is generally regarded as an "isolated case" (in some cases the second and third time).

<u>Comments</u>: Human beings consider a mistake in analysis or calculations as an affront. If something does happen and no action is taken, it is an even bet that it will happen again.

DEFINITIONS

MTBF - MEAN TIME BETWEEN FAILURES

Definition: The total number of operating hours for a given component or system divided by the number of unscheduled removals of that component or system.

Comments: The word "failure" is not used in the true sense as defined herein. In practice, "failures" consist of unscheduled removals because of detection of incipient failures, an indication of failure, right or wrong, and actual failures.

MTBR - MEAN TIME BETWEEN REMOVALS

Definition: The total number of operating hours for a given component or system divided by the number of unscheduled plus scheduled removals (TBO) of that component or system.

APPENDIX II

H-3, H-53, and H-54 Transmission System Drawings

Main Transmissions and Drive-Train Arrangement

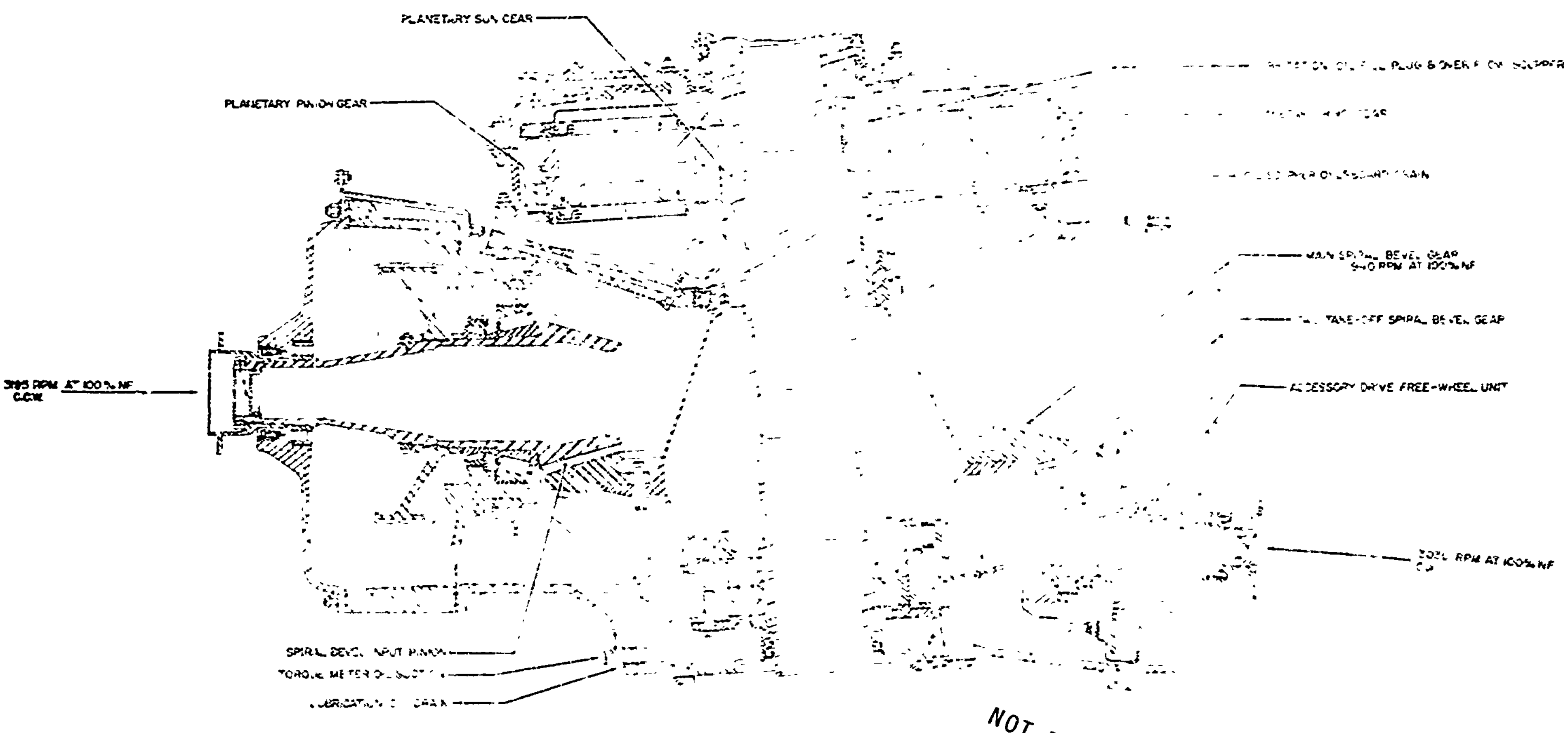


FIGURE 15 • SHEET 1

MAIN GEAR BOX CUTAWAY
6135-22000

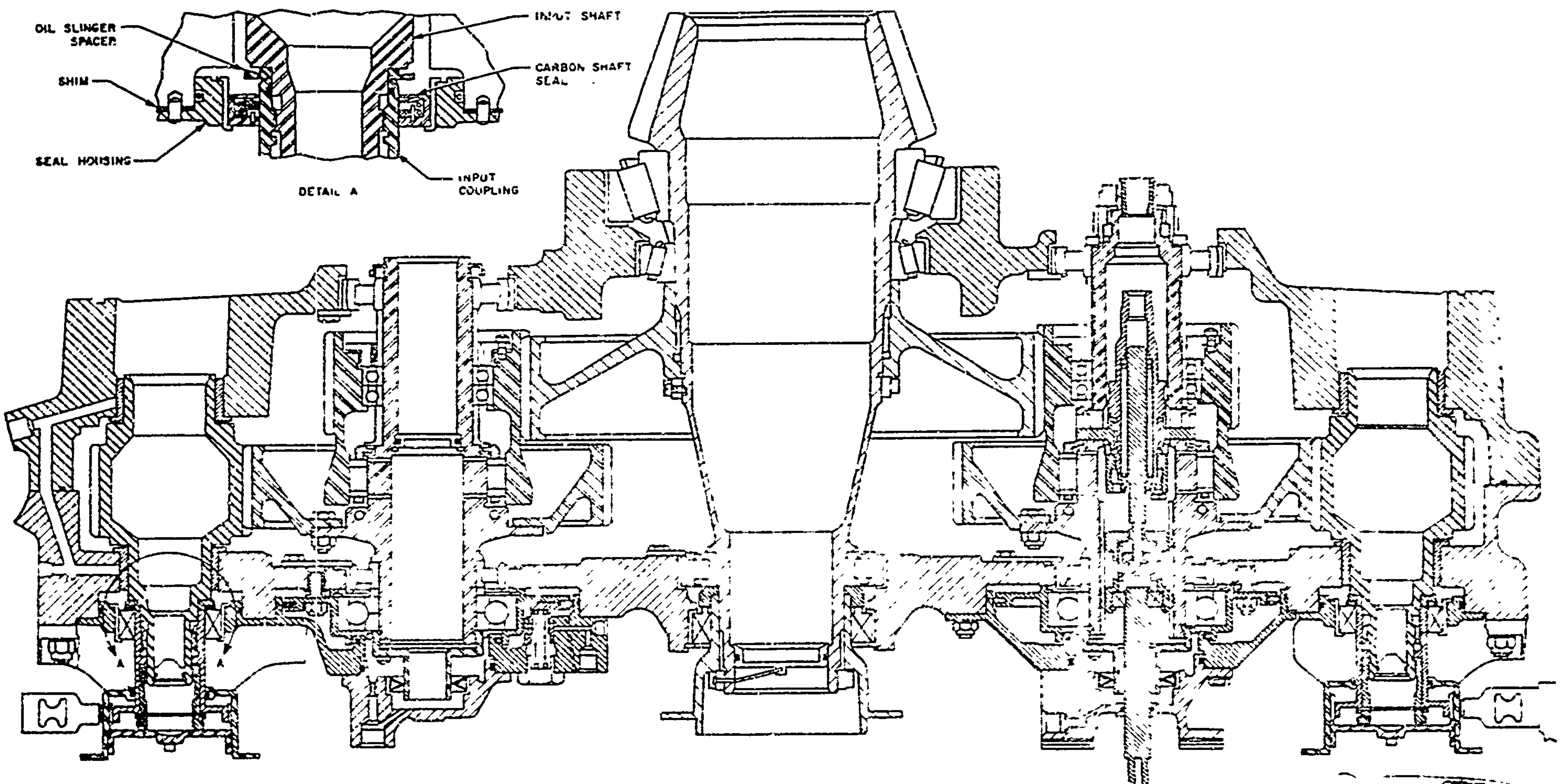
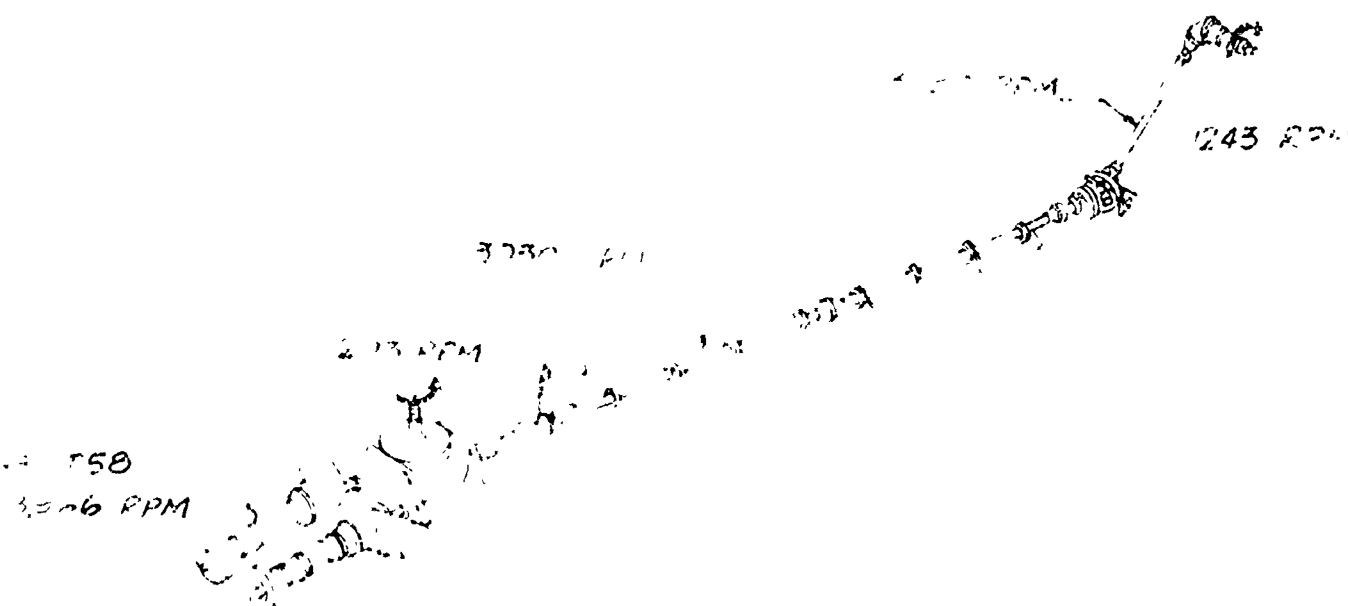
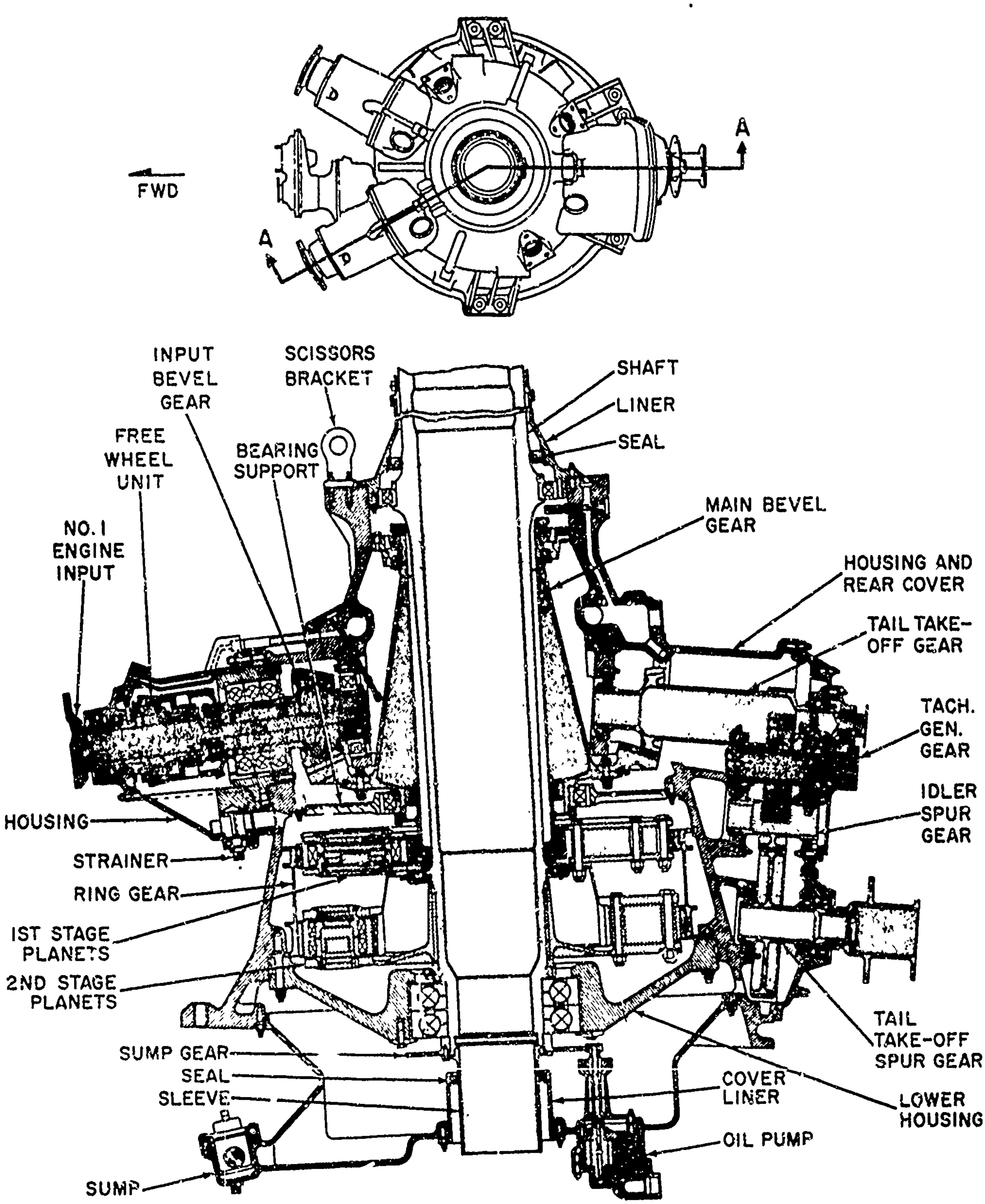


FIGURE 15 SHEET 2
MAIN GEAR BOX INPUT HOUSING ASSEMBLY
6135-20605


ARMY

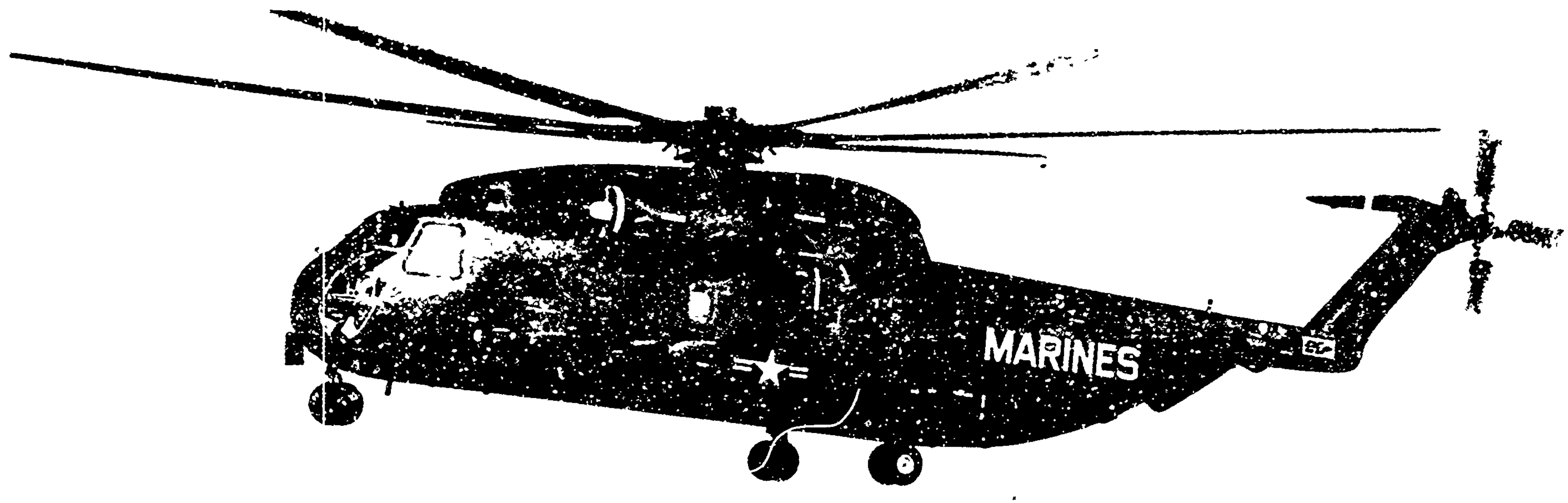

T58



SECTION A--A

MAIN GEAR BOX CUT-A-WAY

FIG. 17



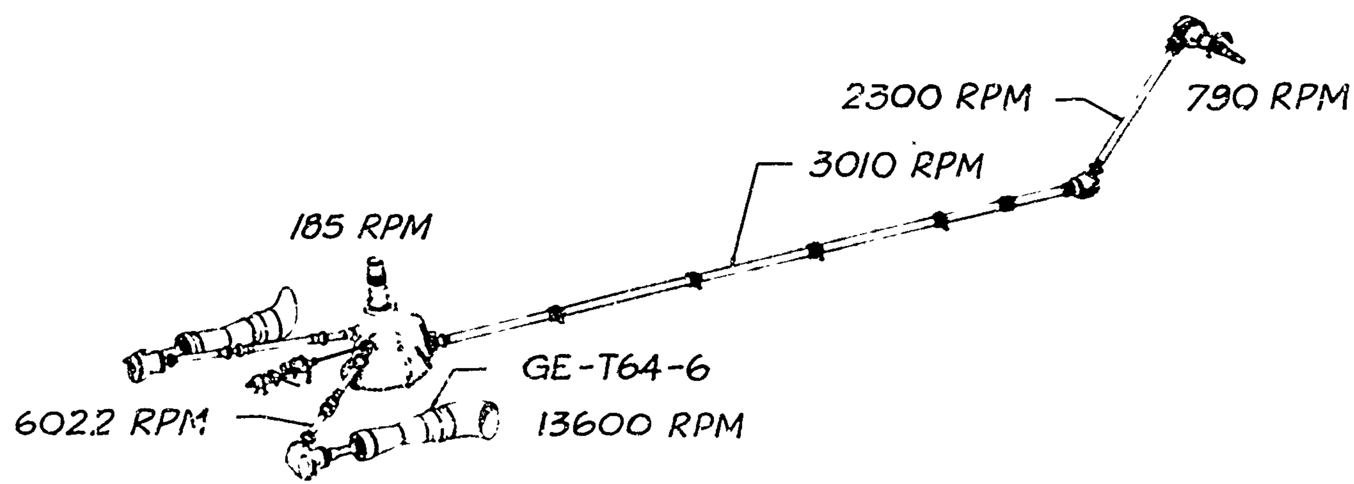


FIG 18

H-53 TRANSMISSION SYSTEM

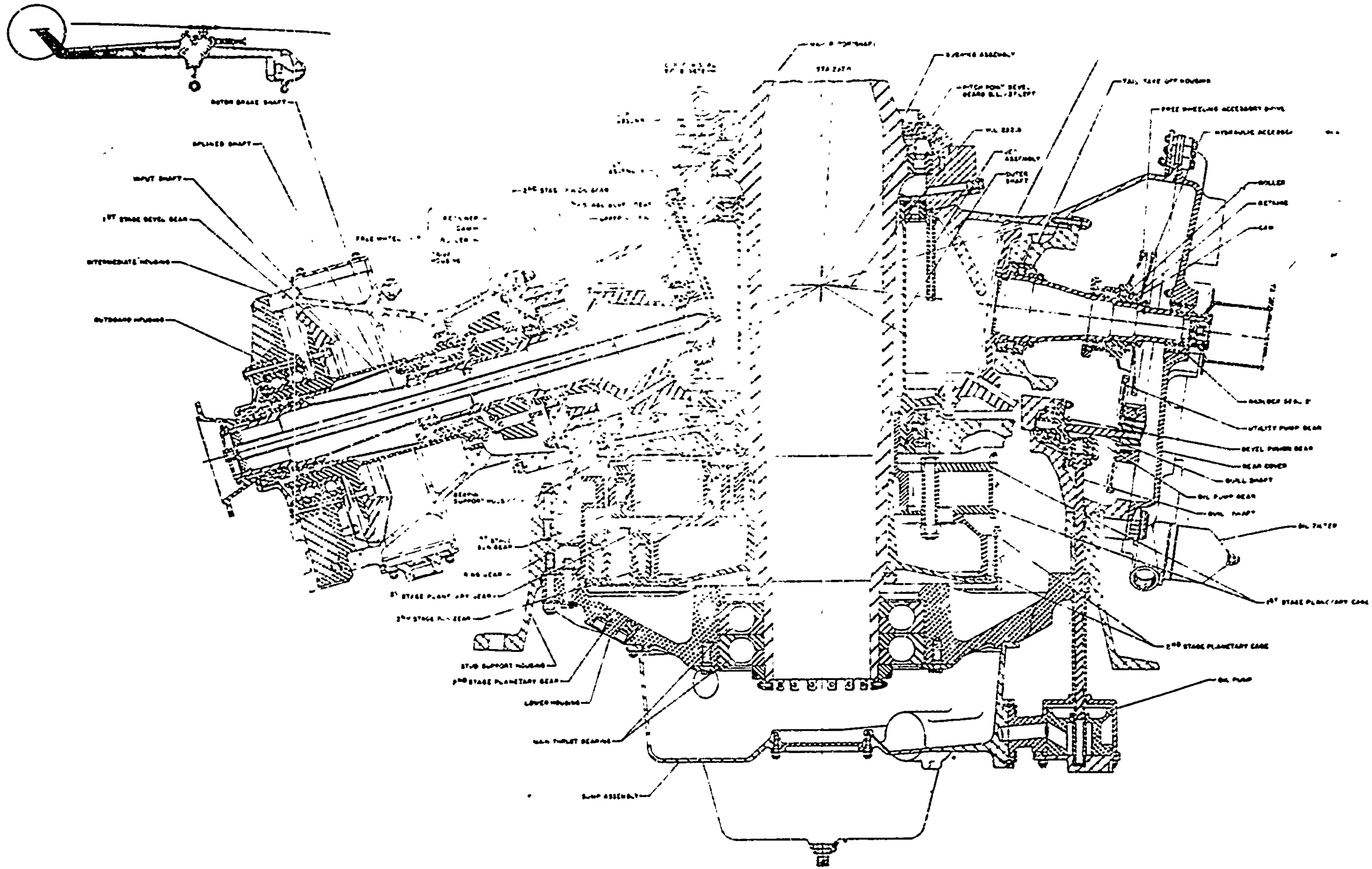


FIG. 19

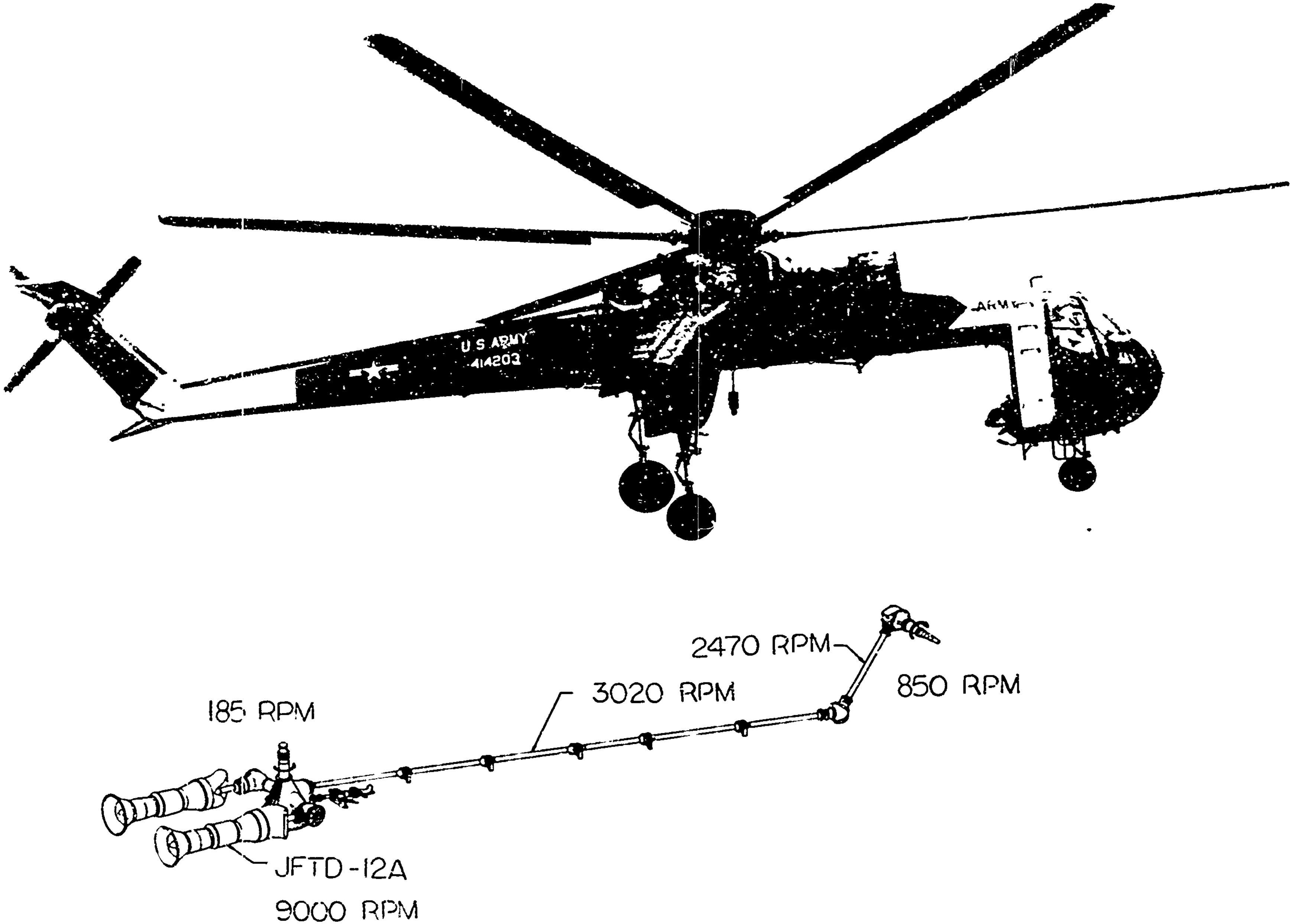


FIG. 2

H-54 TRANSMISSION SYSTEM

TEST FACILITIES

The H-3, H-53 and H-54 Transmission System components reviewed in this report were tested on the Sikorsky Aircraft test facilities shown in the next few pages.

The bench test facilities are used for R & D testing and production acceptance testing. Flight power and loading parameters are simulated in the test box by means of regenerative loop arrangements, which require only a fraction of the normal input horsepower.

For the main transmission rigs, the installation consists of the test box, a dummy box and sundry commercial connecting gearboxes, with shafting and couplings to link like power input shafts, main rotor shafts, and power take-off shafts into continuous loops. Torques are applied to the loops by one of several methods, as follows:

- Through the shaft couplings during installation.
- By rotating the stationary ring gear in the dummy box.
- By rotating the entire dummy gearbox, or commercial reduction gearbox.
- By hydraulic pressure displacing helical gearing in the axial direction.

The latter three methods permit change of torque while the rig is in operation. In addition, flight magnitude thrust loads and moments are applied to the main rotor shaft of the test box. The entire system is rotated at normal operating speed by means of an electric motor (or motors).

Intermediate and tail transmissions are integrated in a common rig with a single loop. The principle is the same as above (utilising test and dummy boxes).

General specifications covering power, gearbox, and cooling limitations are tabulated for each of the facilities on the following pages. Many of these facilities are shown in Figures 21 through 23.

TABLE VII

SIKORSKY AIRCRAFT TEST FACILITIES

Facility	General Application	Power Available	Regenerative Loop Coupling Commercial Gearbox			Ventilation Cooling Capacity	
			Ident.#	Ratio	Rating	Blower	Exhaust
Cell #1	CH-53A Main LHI	(2) 500 H.P.	SL65T-1002	1:3.383	4000 H.P.	25000 CFM	24000 CFM (approx.)
	RHI TTO Output	1780/890 rpm	SL65T-1002 SL65T-1001 SL65T-1003	1:3.383 1:1 1:1	4000 H.P. 1825 H.P. 8000 H.P.	13000 CFM	12000 CFM
Cell #2	S-61 Main	(2) 150 H.P. 1750/860 rpm 1750 rpm	H-23585-18864 4081-1-58322 4081-1-58323	8:684:1 1:1 1:1	3000 H.P. 500 H.P. 500 H.P.	13000 CFM	12000 CFM
Cell #3	CH-53A Tail & Inter-mediate	150 H.P. 1180/590 rpm	SL65T-1026	1:1.72	1825 H.P.	13000 CFM	12000 CFM
Cell #4	CH-54A Nose (R.H.)	300 H.P. 3550/1775 rpm	SL65T-1018	1:1.705 1:3.85	4000 H.P.	13000 CFM	12000 CFM
Cell #5	CH-53A Nose (L.H.)	300 H.P. 3550/1775 rpm	SL65T-1018	1:1.705 1:3.85	4000 H.P.	6000 CFM	Vented
Cell #6	CH-53A Accessory		65356-04042-011				
Cell #7	S-61 Tail & Intermediate	40 H.P. 3545/1775 rpm	21354 21349	1.06:1	600 H.P.	6000 CFM	Vented

TABLE VII (continued)

Facility	General Application	Power Available	Regenerative Loop Coupling Commercial Gearbox S/N	Ratio	Rating	Ventilation Cooling Capacity Blower	Exhaust
Bldg. 7	S-56/64 Tail & Intermediate	40 H.P. 3600/1800 rpm	29561 29562	1.04:1 1.04:1	600 H.P. 600 H.P.	6500 CFM	Vented
	S-58 Tail & Intermediate	40 H.P.	21347 21348	1.06:1 1.06:1	300 H.P. 300 H.P.		
Bldg. 8	S-51 Main	25 H.P. U.S. Varidrive					
	S-62 Main	200 H.P. 900/450 rpm	5922164 5922165 24622 17124	7.4:1 7.4:1 3:1 4.65:1	26000"# 26000"# 5000"# 360000"#		
	S-58/55 Main	150 H.P. 1180/590 rpm	17125 17166 21353 21350	4.65:1 3:1 1.06:1	360000"# 42000"# 300 HP	Not Available	Not Available
	S-55/62 Tail & Intermediate	15 H.P. 1745 rpm	Belt Drive				
	S-61R Intermediate	150/75 H.P. 900/450 rpm	23474 23476	3:1 3:1	50000"# 50000"#	20000 CFM	Vented
2000 HP Main Rotor Test Stand	S-56	2000 H.P. Dynamometer	19380 19381 23489	3:1 3:1 2.96:1	44000"# 40000"# 1400000"#		Vented

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13. ABSTRACT

This report presents the results of a six month study of test service and overhaul experience on the transmission system components of H-3, H-53, and H-54 helicopters. The study was conducted to determine the relative effectiveness of bench, tie-down and flight testing in revealing transmission system modes of malfunction or failure.

Failure data for transmissions of all three aircraft were made to determine failure trends and rates of failure. An analysis of these data, overhaul information and component costs was conducted to determine the effectiveness of current overhaul practices and recommendations for transmission operating intervals are offered.

An investigation of the relative costs spent on testing, production and spare transmission overhaul, and modifications (ECP's) has been made for the H-3 and H-53 which underwent full military qualification test programs.

A dicussion of the goals of transmission development is included along wit a suggested transmission test program.

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